A Value Focus Thinking Approach

to the Academic Course Scheduling Problem

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| | | | Form Approved<br>OMB No. 0704-0188 |
|---|---|---|---|
| **Report Documentation Page** | | | |

| 1. REPORT DATE<br>**1998** | 2. REPORT TYPE<br>**N/A** | 3. DATES COVERED<br>**-** |
|---|---|---|

| 4. TITLE AND SUBTITLE<br>**A Value Focus Thinking Approach to the Academic Course Scheduling Problem** | 5a. CONTRACT NUMBER |
|---|---|
| | 5b. GRANT NUMBER |
| | 5c. PROGRAM ELEMENT NUMBER |
| 6. AUTHOR(S) | 5d. PROJECT NUMBER |
| | 5e. TASK NUMBER |
| | 5f. WORK UNIT NUMBER |

| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br>**Air University Press Maxwell AFB, AL 36112-6615** | 8. PERFORMING ORGANIZATION REPORT NUMBER |
|---|---|
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | 10. SPONSOR/MONITOR'S ACRONYM(S) |
| | 11. SPONSOR/MONITOR'S REPORT NUMBER(S) |

| 12. DISTRIBUTION/AVAILABILITY STATEMENT<br>**Approved for public release, distribution unlimited** |
|---|

| 13. SUPPLEMENTARY NOTES |
|---|
| 14. ABSTRACT |
| 15. SUBJECT TERMS |

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT<br>**UU** | 18. NUMBER OF PAGES<br>**136** | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT<br>**unclassified** | b. ABSTRACT<br>**unclassified** | c. THIS PAGE<br>**unclassified** | | | |

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## *Acknowledgements*

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AFIT/GOR/ENS/98M-14

## *Abstract*

In 1997, the School of Engineering of the United States Air Force Institute of Technology began exploring ways of automating the academic course scheduling process. The administration desired an expedient approach for course scheduling which supports the institute's mission of "providing scientific and technological education" to officers from all branches of military service, as well as international military forces. The scheduling approach needed to be flexible, efficient, and represent the institute's values and principles. Decision Analysis (DA) and specifically, Value Focused Thinking (VFT), is used to decompose the complex problem of academic course scheduling and determine the factors that are important in a schedule. An MS Excel based Decision Support System generates a Mixed Integer Program (MIP). The MIP formulation combines the institute's goals with facility constraints, faculty preferences, student preferences, and administration guidance to develop an academic course schedule representative of the institute's values.

# Chapter 1

# Introduction

The research documented in this thesis is in response to the Office of Academic Operations of the School of Engineering of the Air Force Institute of Technology's request for support. The staff of the Office of Academic Operations is responsible for scheduling the courses offered by the School of Engineering on a quarterly basis. In an effort to reduce the amount of time required to produce a schedule, an efficient approach to academic course scheduling was sought. Decision Analysis and Value Focused Thinking (VFT) were used to decompose the course scheduling problem and determine the important issues inherent in a quality schedule.

Our goal is to provide the Office of Academic Operations with a tool that will efficiently solve the academic course scheduling problem for the School of Engineering and reduce the time and effort expended by the staff in the production of a schedule. We have done this through the development of an Educational Decision Support Scheduling System (EDSSS). EDSSS combines an MS Excel based spreadsheet and suite of Visual Basic Modules, with the IBM Mixed Integer Solver named Optimization Subroutine Library (OSL).

The remainder of this thesis explains the theoretical background and methodology used in the development of EDSSS. Textual copies of the Visual Basic Modules and a

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user manual are included. This thesis is organized so that Chapter 2 is a stand-alone article on our research, suitable for submission to an academic journal. Chapter 3 outlines some obvious extensions to this work.

Appendix A contains the completed schedule for the 1998 Spring Quarter for the School of Engineering of AFIT. Appendix B provides the Visual Basic source code for the electronic questionnaire used in EDSSS, while Appendix C gives the Visual Basic source code for the modules used by the mixed integer problem generator portion of EDSSS. Appendices D through G show the results for each of the four scheduling variations obtained from IBM's mixed integer solver, Optimization Subroutine Library (OSL). Appendix H provides a user manual for EDSSS. Finally, Appendix I and J contain the Preference Table and Ed Plan Query used by EDSSS in the development of the Spring Quarter 98 schedule.

# Chapter 2

# Introduction

The School of Engineering (EN) of the United States Air Force Institute of Technology (AFIT), located on Wright-Patterson Air Force Base, Ohio, provides ABET accredited post-graduate education to officers in the U.S. Air Force, along with officers from other branches of service and international military forces. The school of engineering has an enrollment of approximately 350 students, and is comparable in size to a small civilian college or secondary school. AFIT's School of Engineering is divided into six departments, each under the direction of a Department Head. The six departments include Aeronautics and Astronautics (ENY), Electrical and Computer Engineering (ENG), Engineering and Environmental Management (ENV), Mathematics and Statistics (ENC), Operational Sciences (ENS), and Engineering Physics (ENP).

Academic course scheduling at the School of Engineering of the United States Air Force Institute of Technology is largely a manual process. The institute's six departments propose days and times for the courses to be offered by that department in the upcoming academic quarter. Students create Education Plans specifying enrollment in courses for the upcoming quarter. The office of Academic Operations gathers the departmental proposals and is challenged with combining the offered times and student education plans into a working course schedule. A working schedule assigns courses to

days, times, and rooms. The schedule must comply with all administrative policy as well as facility constraints. The staff of the office of Academic Operations performs this task by hand, with a working schedule often requiring multiple revisions and over 65 person-hours.

This paper documents a new approach to academic course scheduling for the School of Engineering of AFIT. The objectives of the research are: (1) to quantify the factors and issues important to EN in a course schedule, (2) to find metrics that can measure how well a schedule addresses the important factors, (3) to create a Decision Support System that will aid the offices of Academic Operations in scheduling future quarters, and (4) to develop a efficient means of solving the academic course scheduling problem for the School of Engineering.

The remainder of this paper is organized in the following manner. The survey of academic course scheduling literature is presented followed by the theoretical background for the Value Focused Thinking (VFT) approach used to decompose and quantify the complex issues. A Mixed Integer Programming (MIP) is developed whose objective maximizes the institute's values and whose implementation efficiently solves the academic course scheduling problem at AFIT. Finally, the results of this research are presented.

## Survey Of Literature

Academic course scheduling is generally broken into two main tracts in the literature: (1) faculty to course assignments and (2) the assignment of courses to days, times, and rooms, herein referred to as course timetabling. This research deals only with

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the latter area, as each course at the School of Engineering for AFIT has been assigned to a faculty member, by departmental process, prior to scheduling.

**Mixed Integer Programming Approach**

Many examinations of the course timetabling problem in the literature present a Mixed Integer Problem (MIP) formulation. Mulvey (1982) presents the following MIP using binary variables, denoted as problem P1.

**Problem P1**: Mulvey's MIP Formulation

$$\text{Maximize} \quad \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}x_{ij} \tag{1}$$

$$\text{Subject To} \quad \sum_{j=1}^{n} x_{ij} = 1 \qquad \text{all } i, \tag{2}$$

$$\sum_{i=1}^{m} k_i x_{ij} \le f_j \qquad \text{all } j, \tag{3}$$

$$\sum_{i\in I_p}\sum_{j\in S_t} x_{ij} \le 1 \qquad \text{all } p,t, \tag{4}$$

$$\sum_{i\in I_r}\sum_{j\in S_t} x_{ij} \le 1 \qquad \text{all } r,t, \tag{5}$$

$$x_{ij} = \{0,1\} \tag{6}$$

where $i$ is defined as a course, and $j$ as a classroom/day/time combination. The binary variable $x_{ij}$ is 1 if course $i$ is taught during the classroom/day/time combination $j$ and 0 otherwise. $I_p$ is an indexed set defining which classes are taught by faculty member $p$, while $I_r$ defines which classes are assigned to student $r$. Finally, $S_t$ is the set of classroom/day/time combinations that occur simultaneously and $c_{ij}$ is a cost coefficient realized when course $i$ is assigned to classroom/day/time combination $j$. The first

constraint, equation (2), ensures that each class is assigned to only one classroom/day/time combination. Equation (3) requires adequate capacity of the classrooms, while (4) and (5) preclude instructors and students from being assigned to two activities at one time (Mulvey: 1989).

Mulvey classifies this MIP formulation as a "well-defined model", meaning the solution can theoretically be found using a standard MIP solution technique, such as branch and bound. However, the large number of binary variables required to implement the MIP formulation led Mulvey (1989) to state that "a realistic size [academic course scheduling] problem cannot be solved within a reasonable length of processing time." For example, consider a timetabling problem in which there are 100 courses to schedule in 10 classrooms. We will restrict the problem further by requiring each course to be started on the hour between 0800 and 1700, thus allowing only 45 time slots per week. This relatively small timetabling problem's formulation would require, 100*10*45 or 45,000 binary variables, rendering the problem computationally intractable by most existing MIP solvers.

Sampson, Weiss, and Freeland (1995) propose a similar MIP formulation to solve the course timetabling problem. As with the Mulvey formulation, the MIP was abandoned "because of the combinatoric nature of the problem" (Sampson, Freeland and Weise: 1995). Mulvey (1989) eventually proposed a relaxation of the MIP and a "man-machine interaction" approach to finding a solution. Man-machine interaction requires user input as the solver executes. Sampson and Weiss (1995), Ferland and Fleurent (1994), and Bloomfield and McSharry (1979) propose heuristic techniques as well as

man-machine interaction to solve the course timetabling problem and develop a working schedule for academic courses.

Alvarez-Valdez, Martin, and Tamarit (1996) developed a tabu search heuristic to solve a timetabling problem for Spanish secondary schools. Costa (1994) also proposes a tabu search approach to course scheduling. In both implementations, a traditional MIP formulation of the academic course scheduling problem is solved to near optimality. Great improvements in CPU time are realized by a tabu search over a Mixed Integer Solver.

**Cost Coefficients**

Although the overriding theme of the academic course scheduling literature proposes heuristic or iterative approaches, the definition of the $c_{ij}$, (cost coefficients) differ. Mulvey proposes a metric, such as the number of occupied seats, be used to determine a cost associated with scheduling course $i$ in classroom/day/time combination $j$ (1982).

Bloomfield and McSherry determine the cost coefficients using instructor preferences (1979). Each instructor is given a choice of either a Monday, Wednesday, and Friday schedule or a Tuesday and Thursday schedule. Additionally, instructors can pick either AM or PM time of day and a type of classroom. As with most of the models, classrooms are grouped by type, e.g. those classrooms having similar capacities, equipment, and so forth. Each instructor provides a preferred choice for a day, time, and room and a ranking of the choices. The heuristic, proposed by Bloomfield and McSherry (1979), tries to satisfy as many preferences as possible. The heuristic initially schedules a day to each instructor who ranked "day" the highest, a time to each instructor who chose

"time" as the highest and a location to each instructor who preferred "room type". The heuristic continues to iterate until a working schedule is found.

Sampson, Freeland and Weiss (1995) also use faculty preferences to determine the cost coefficients. Additionally, they incorporated the students' request to enroll in specific classes. Their model uses a "modified-local search heuristic" to develop a timetable. Furthermore, an enrollment-construction heuristic was used to maximize the number of students who are able to attend the courses they desired. This iterative approach is used to find a schedule that works within faculty preferences and constraints, while attempting to maximize the number of courses available to interested students (Sampson, Freeland and Weiss, 1995).

Graves, Schrage and Sankaran (1993) implement an auction method to incorporate student preferences. Students are allowed to pick from an already establish timetable. Each student is given a place in a queue. The number of preferences satisfied during the previous quarter's schedule primarily determines this placement. For subsequent class registration an inverse order of scheduling permitted students a priority advantage based upon the number of previously scheduled preferences. In other words, positioning in the queue is relative to the extent to which preferences were accommodated by previous schedules.

## VFT Theoretical Model

Although the formulation of the MIP is straight forward, the number of binary variables associated with a course timetabling problem require a computationally intractable amount of time for solution. The goal to produce a course schedule is a difficult, complex problem. Decision analysis, a branch of operations research, "provides

structure and guidance for thinking systematically about hard decisions" (Clemens, 1996).

Decision analysis requires the involvement of a decision maker, presumably the Dean of the institution, for the academic course scheduling problem. The decision maker's values are the key elements in the process. According to Clemens, the decision analysis process can be broken down into key elements or steps. As these steps are followed, a clearer understanding and solution to the problem may be available. This process decomposes the problem to make it simpler. Clemens points out that "decomposition is the key to decision analysis" (Clemens, 1996). The following flow chart from Clemens illustrates the decision analysis process.

```
        ┌─────────────────────────┐
        │   Identify the decision │◄──────────┐
        │     situation and       │           │
        │ understand the objectives│          │
        └─────────────────────────┘           │
                    │                          │
                    ▼                          │
        ┌─────────────────────────┐           │
        │   Identify alternatives.│◄──────────┤
        └─────────────────────────┘           │
                    │                          │
                    ▼                          │
        ┌─────────────────────────┐           │
        │ Decompose and model the │           │
        │        problem:         │◄──────────┤
        │  1. Model of problem    │           │
        │  2. Model of preferences│           │
        └─────────────────────────┘           │
                    │                          │
                    ▼                          │
        ┌─────────────────────────┐           │
        │ Choose the best alternative.│       │
        └─────────────────────────┘           │
                    │                          │
                    ▼                          │
        ┌─────────────────────────┐           │
        │   Sensitivity analysis  │           │
        └─────────────────────────┘           │
                    │                          │
                    ▼              Yes         │
              ╱─────────────╲─────────────────┘
             ╱ Is further analysis ╲
             ╲    needed?          ╱
              ╲─────────────╱
                    │
                    │ No
                    ▼
        ┌─────────────────────────┐
        │    Implement the        │
        │  chosen alternative.    │
        └─────────────────────────┘
```
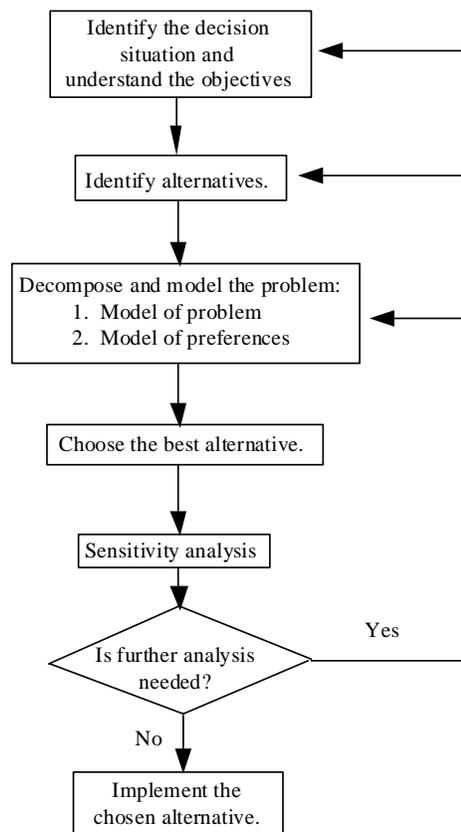
**Figure 1.  Decision Analysis Process Flowchart (Clemens, 1996)**

Note the process is iterative. The desired result may always be improved, through continual refinement of the decision situation, the addition of new alternatives, or refined insight and further decomposition.

To ascertain a precise understanding, the decision situation must be well defined and the objectives clearly outlined, prior to decomposing the problem. There are two prevailing thoughts with regard to this effort. Keeney (1992) identifies the first approach as "alternative-focused thinking". This approach concentrates on developing potential solutions to the problem, known as alternatives, and using the differences in the alternatives for evaluation. A comparison of two or more working schedules created manually by staff of the office of Academic Operation would be an example of this approach. Keeney (1992) does not favor this approach, claiming it is backwards; "it puts the cart of identifying alternatives before the horse of articulating values".

**Value Focused Thinking**

Conversely, Keeney (1992) concentrates on an approach he calls "value-focused thinking". Contrary to "alternative-focused thinking", this approach concentrates on soliciting from the decision maker and others who are knowledgeable about the problem, a set of values or goals, which address what is important in the decision situation. Having identified these goals, they are structured into general and specific objectives, that if achieved will realize the established goals. These objectives are then organized into a value hierarchy. A value hierarchy structures these objectives such that the upper level values are more general and have a greater impact on the overall value of the hierarchy, while lower level values further describe the upper levels. The most specific values are then given evaluation measures or metrics that show how well an alternative has met that

value.  Furthermore, each level of the value hierarchy can be weighted based on the decision maker's preference for obtaining that value over other values at the level. Below is an example of a value hierarchy with weights.

```
                        ┌──────────────┐
                        │ Overall Goal │
                        └──────────────┘
            ┌──────────────────┼──────────────────┐
┌────────────────────┐ ┌────────────────────┐ ┌────────────────────┐
│ General Objective 1│ │ General Objective 2│ │ General Objective 3│
│    Wgt = 0.25      │ │    Wgt = 0.5       │ │    Wgt = 0.25      │
└────────────────────┘ └────────────────────┘ └────────────────────┘
                    ┌─────────┴─────────┐
        ┌────────────────────┐ ┌────────────────────┐
        │ Specific Obective 1│ │ Specific Objective 2│
        │     Wgt 0.33       │ │    Wgt = 0.66       │
        └────────────────────┘ └────────────────────┘
```
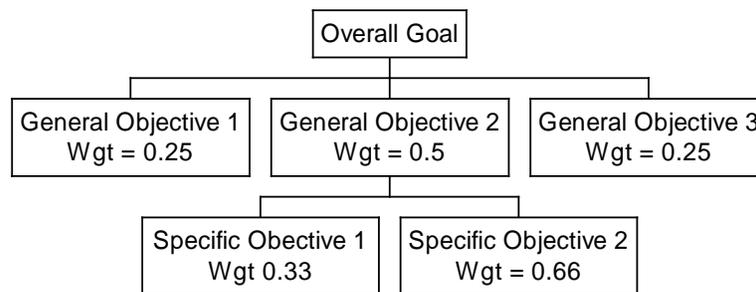
**Figure 2.  Value Hierarchy Example**

The value hierarchy can be used to inspire the creation of new alternatives that had not been previously considered.  According to Kirkwood (1997), "When you know what you are trying to accomplish, then you can attempt to identify alternatives that address these objectives".  Furthermore, the value hierarchy provides a means for evaluating various alternatives.  The use of the evaluation measures, associated with the most specific values, provide "formal methods… [using] a mathematical function to combine evaluation measures from the hierarchy" that can be used to rank alternatives and determine the best solution to a difficult problem (Kirkwood, 43:1997).

**Multiple Objective Value Analysis**

Once a value hierarchy has been established, evaluation measures or metrics are used to capture an alternative's worth with regards to a specific objective.  Evaluation measures are attributes that provide an objective evaluation of performance.  Single

dimensional value functions translate the metric performance into a unitless quantity known as value. Single dimensional value functions are either monotonically increasing or decreasing (Kirkwood, 1997).

Weights are determined for each evaluation measure. The weights are used to show "different degrees of importance attached" to the performance of an alternative with regards to a specific evaluation measure. That is, if evaluation measure (1) is weighted more heavily than evaluation measure (2), "variations over the range for [evaluation measure (1)] are more important than variations over the range for [evaluation measure (2)] when using this set of weights" (Kirkwood, 1997).

Once the weights and single dimensional value functions are established, the final value or overall value of each level of the value hierarchy becomes

$$v(X_1, X_2, ..., X_n) = w_1 v_1(X_1) + w_2 v_2(X_2) + ... + w_n v_n(X_n) \qquad (7)$$

where $v_i(X_i)$ is the value determined using the single dimensional value functions associated with evaluation measure or attribute $X_i$ and $w_i$ is the weight given to that evaluation measure (Kirkwood, 1997). This assessment of value is called an additive value function.

Kirkwood (1997) states that the attributes, $X_i$, of an additive value function must have mutual preferential independence. Mutual preferential independence exists if Y is preferentially independent of Z, where Y and Z are a partition of $\{X_1, X_2, ..., X_n\}$. Kirkwood (1997) shows that "Y is preferentially independent of Z if the rank ordering of alternatives that have common levels for all attributes in Z does not depend on these common levels." These assumptions will later be shown to hold for this research.

# Methodology

Academic Course Scheduling can be decomposed into a series of separate decisions. A decision is made whether to schedule course $i$ on day/time $j$ and in room $r$ or not. A schedule is created once a decision is made for each course $i$. Obviously, there exist myriad different combinations of decisions that all create a schedule. Therefore, an additional decision chooses the "best" schedule from the set of possible schedules. The methodology herein uses this view of the academic course scheduling problem. The decision maker, for this research was the Dean of the School of Engineering; his decision was supported by his staff, and the Department Heads.

## Influence Diagram

The effort began with the creation of an influence diagram. An influence diagram is a visualization tool that allows a decision maker to annotate the decision to be made and the important factors that influence the value of the result of the decision. The influence diagram for the course scheduling problem at AFIT is shown in Figure 3. Directives from the Dean of the School of Engineering, as well as department, faculty and student preferences are factors that influence the value of the decision to schedule course $i$ on day/time $j$ in room $r$. The outcome of the individual course scheduling decisions as well as room capacities, room availability, instructor conflicts and student conflicts effect the value of the overall schedule. The influence diagram as a whole defines the decision situation.
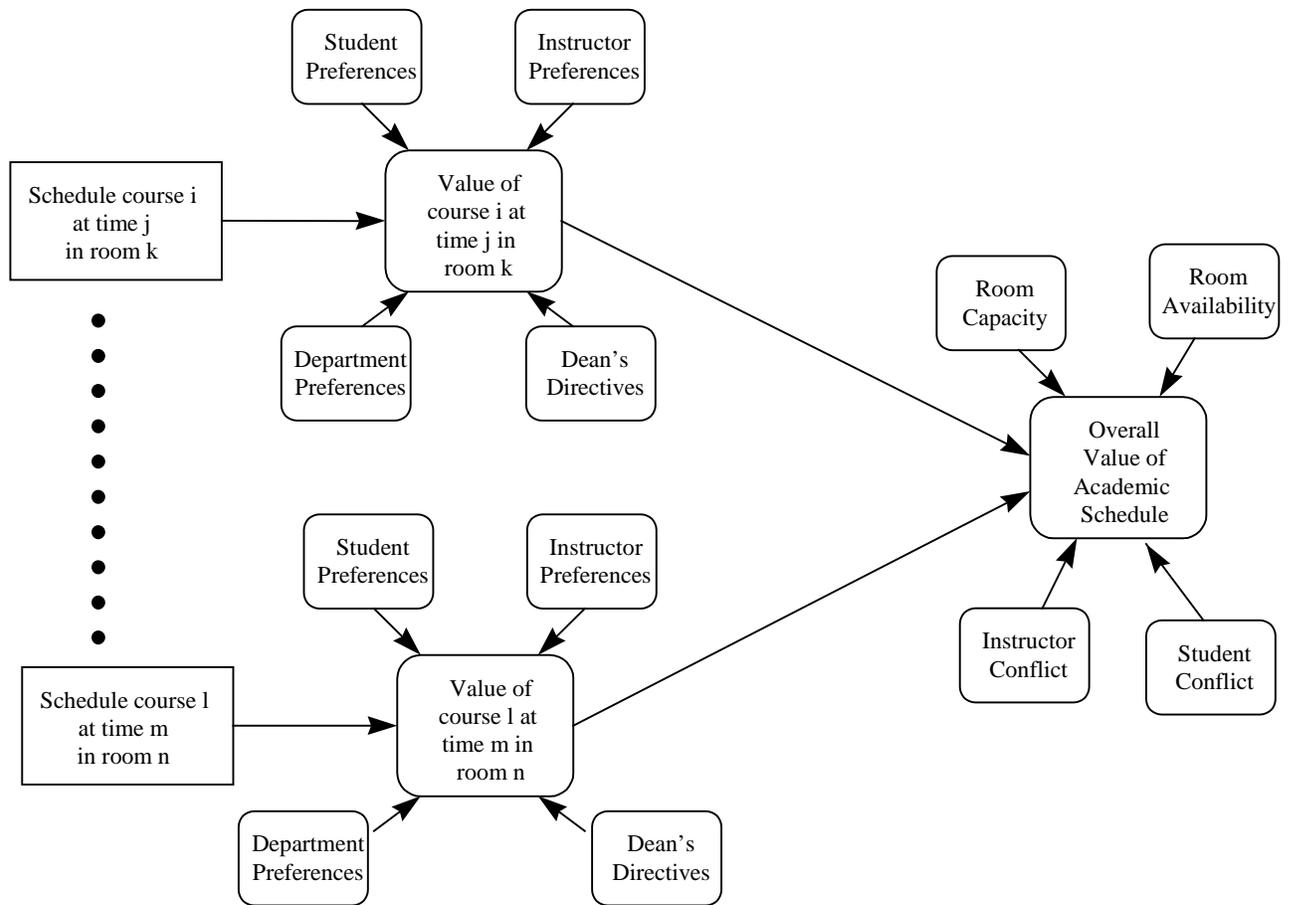
**Figure 3.  Influence Diagram**

Rectangles represent decisions, while rounded boxes represent values.  The arrows show

a direct influence imparted by a decision or value.

**Value Hierarchy**

The influence diagram aids in the creation of the value hierarchy.  A value

hierarchy is developed by working closely with the decision maker to decompose his

decision into the factors that influence the decision situation.  These are placed within the

levels of the hierarchy.  The value hierarchy must be mutually exclusive and collectively

exhaustive. Figure 4 shows the value hierarchy for the decision situation illustrated by the influence diagram in Figure 3.
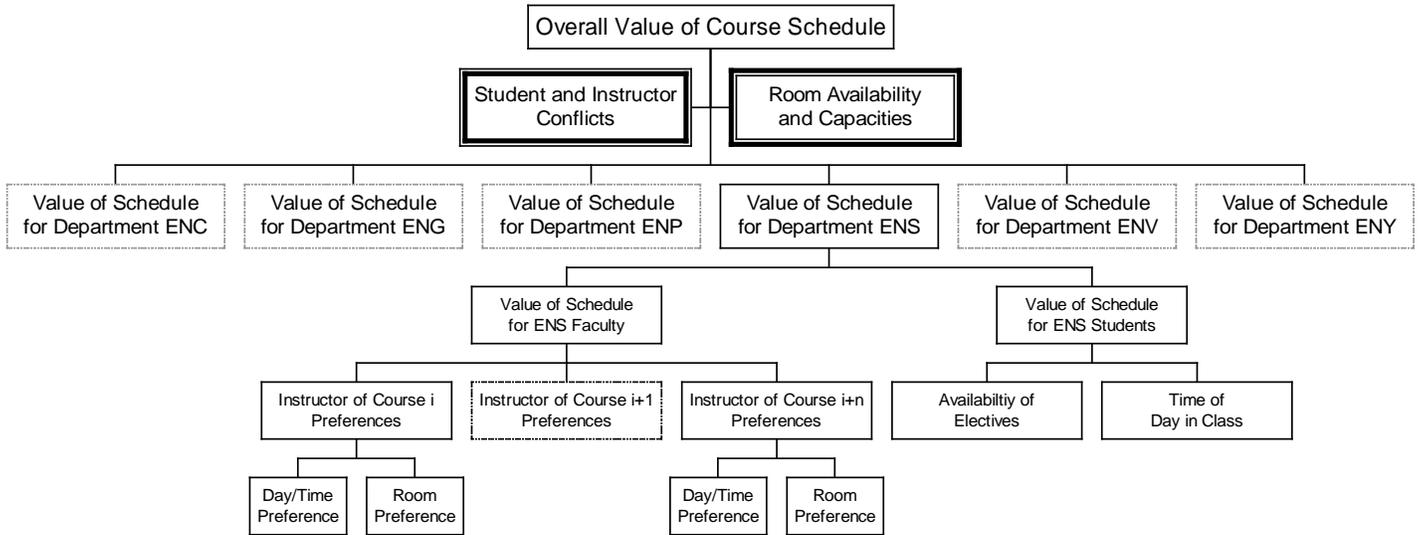


**Figure 4.  Value Hierarchy**

The value hierarchy has five distinct levels and two go/no-go criteria. The go/no-go criteria are shown in bold outline and are defined later. The value of the schedule for each department has the most influence on the overall value of the schedule. The decision maker, through weighing of the values at this level, determines the contribution of each department's value towards the overall value. In a similar fashion, the contribution of the values from lower levels on upper levels is dictated by weighting. The weights of any level of the hierarchy must be a convex combination. Therefore, the following equations govern the weights used in the calculation of value.

$$\sum_{D=1}^{6} w_D = 1 \tag{8}$$

$$w_{f_D} + w_{s_D} = 1 \qquad \text{for all } D \tag{9}$$

$$\sum_{i_D} w_{i_D} = 1 \qquad \text{for all } D \tag{10}$$

$$w_{j_{i_D}} + w_{r_{i_D}} = 1 \qquad \text{for all } i_D \tag{11}$$

where $w_D$ is the weight of each department, $w_{fD}$ is the weight of the faculty preferences in department $D$ and $w_{sD}$ is the weight of the students in department $D$. $w_{iD}$ is defined as the weight of each course in department $D$, $w_{jiD}$ is the weight of day/time preference $j$ for course $i_D$ and, $w_{riD}$ is the weight of room preference $r$ for course $i_D$. The Dean assigns the departmental weighting, while the respective Department Heads assign the faculty and course weightings. Instructors assign day/time scenario and room group weights.

For the purposes of this research for AFIT, the weight of the student's values, $w_{sD,}$ for each department was set to zero, making $w_{fD}$ equal to1. This was done for two reasons: (1) the value of the availability of electives is covered by the go/no-go criteria of a deconflicted schedule, and (2) as active duty military officers attending course is considered a student's primary duty and additional duties that may make a day/time scenario unattractive are kept to a minimum. Of course, student weighting can be utilized in a different operational setting.

The following value function describes the contribution of day/time preference $j$ of course $i$ on the overall value of the schedule.

$$V_{i_D j} = w_D \cdot w_{f_D} \cdot w_{i_D} \cdot w_{j_{i_D}} \cdot v_{j_{i_D}} \tag{12}$$

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where $V_{iDj}$ is the contribution to the overall value and $v_{jiD}$ is the value of scheduling course $i$ in day/time $j$. In a similar manner, equation (13) describes the contribution of room preference $r$ of course $i$.

$$V_{i_{D}r} = w_D \cdot w_{f_D} \cdot w_{i_D} \cdot w_{r_{i_D}} \cdot v_{r_{i_D}} \tag{13}$$

where $V_{iDr}$ is the contribution to the overall value and $v_{riD}$ is the value of scheduling course $i$ in room $r$.

The value of $v_{jiD}$ and $v_{riD}$ is determined using a single dimensional value function. The single dimensional value function is a monotonically decreasing step function that transforms preference numbers into a unitless property known as value. Figure 5 shows the value function used to determine the value of both the instructors' day/time and room preferences. This value function is used for all courses scheduled. The department heads unanimously agreed to the slope and shape of the function.
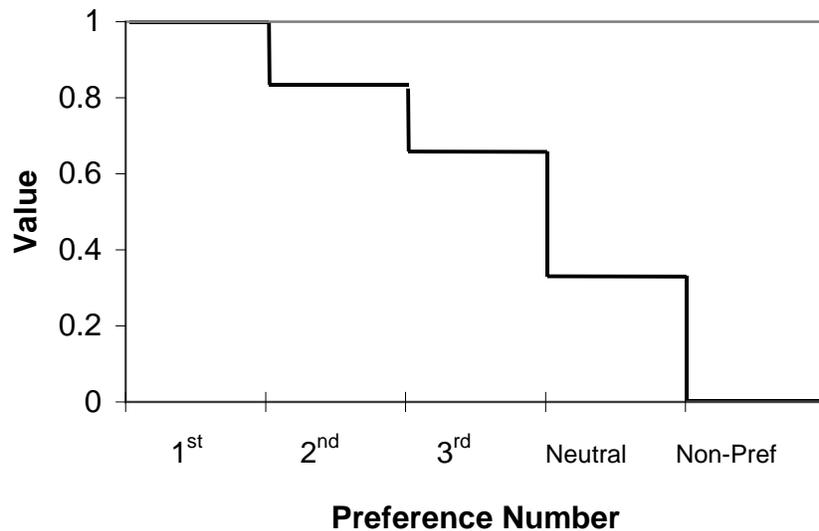
**Figure 5. Single Dimensional Value Function**

Therefore, course i's total contribution on the overall value, $V_{iD}$, is found by combining equations (12) and (13).

$$V_{i_D} = V_{i_D j} + V_{i_D r} = w_D \cdot w_{f_D} \cdot w_{i_D} \left( w_{j_{i_D}} \cdot v_{j_{i_D}} + w_{r_{i_D}} \cdot v_{r_{i_D}} \right) \tag{14}$$

Finally, summing the value of all courses and multiplying the quantity by the binary go/no-go variables, $C_s$ and $R_s$, determines the overall value, $V_s$, of schedule $s$. The binary variable $C_s$ is 1 if no student or instructor is assigned to attend any two courses at simultaneous days and times and 0 otherwise. The individual's education plan specifies the courses for which the student is enrolled. This go/no-go criteria is essential to a academic course schedule because of the 18 month window in which all students assigned to AFIT must take *all* required courses for graduation and *all* electives that directly support their research. The binary variable $R_s$ is 1 if: (1) all courses assigned to a room group do not have an enrollment that exceed the capacity of the rooms in that group and, (2) the number of courses scheduled at any time does not exceed the number of rooms available. $R_s$ is equal to 0 if either of the above condition is not met.

$$V_s = C_s \cdot R_s \Big|_{i_D} V_{i_D} \Big| \tag{15}$$

Clearly the most valuable schedule can be found by comparing the overall value, $V_s$, of every possible schedule. A Mixed Integer Program is used to make these comparisons and determine the most valuable schedule.

**Mixed Integer Program**

The formulation of the Mixed Integer Program (MIP) requires the definition of a binary variable $x_{ijk}$, where $i$ is a three-digit course index number, $j$ is a three-digit day/time scenario index and $k$ is a room group index number. A course index number is assigned to each course to be scheduled. A day/time scenario consists of a set of days per week on which a course is taught combined with a time on each day, herein referenced as scenarios.

The scenarios used in this research require identical time periods be used on each day of the week. Additionally, the time periods are of equivalent length equal to 1 hour. These requirements are not essential for the formulation, but reduce the number of possible scenarios and are representative of standard academic course schedule. In general, a course that meets from 0800 – 0900 on Monday will meet during the same hours on subsequent days of the week. Table 1 shows the scenarios, by number of hours per week a course meets and an index number assigned to each scenario. When a time range is given, the scenarios are numbered in increasing order as the start hour increases throughout the days of the week.

## Table 1. Day/Time Scenarios

|  | Days of the Week | Start Times (on the hour) | Scenario ID # |
|---|---|---|---|
| 1 Hour Class• | M | 0800 -1600 | 001 - 009 |
|  | T | 0800 -1600 | 010 - 018 |
|  | W | 0800 -1600 | 019 - 027 |
|  | R | 0800 -1600 | 028 - 036 |
|  | F | 0800 -1600 | 037 - 045 |
| 2 Hour Class• | M | 0800 -1500 | 046 - 053 |
|  | T | 0800 -1500 | 054 - 061 |
|  | W | 0800 -1500 | 062 - 069 |
|  | R | 0800 -1500 | 070 - 077 |
|  | F | 0800 -1500 | 078 - 085 |
| 3 or 4 Hour Class• | MW | 0800 -1500 | 086 - 093€ |
|  | TR | 0800 -1500 | 094 - 101€ |
|  | MR | 0800 -1500 | 102 - 109€ |
|  | MF | 0800 -1500 | 110 -117€ |
|  | TF | 0800 -1500 | 118 - 125€ |
| 3 Hour Class | MWF | 0800 -1600 | 126 - 134€ |
|  | MTR | 0800 -1600 | 135 - 143€ |
|  | MTF | 0800 -1600 | 144 - 152€ |
|  | MWR | 0800 -1600 | 153 - 161€ |
|  | MRF | 0800 -1600 | 162 - 170€ |
|  | TWF | 0800 -1600 | 171 - 179€ |
|  | TRF | 0800 -1600 | 180 - 188€ |
| 4 Hour Class | MTWR | 0800 -1600 | 189 - 197€ |
|  | MTWF | 0800 -1600 | 198 - 206€ |
|  | MTRF | 0800 -1600 | 207 - 215€ |
|  | MWRF | 0800 -1600 | 216 - 224€ |
|  | TWRF | 0800 -1600 | 225 - 233€ |
| 6 Hour Lab | MW | 0900 | 234€ |
|  | MW | 1300 | 235€ |
|  | TR | 0900 | 236€ |
|  | TR | 1300 | 237€ |
| 3 Hour Lab | M | 0900 | 238€ |
|  | M | 1300 | 239€ |
|  | T | 0900 | 240€ |
|  | T | 1300 | 241€ |
|  | W | 0900 | 242€ |
|  | W | 1300 | 243€ |
|  | R | 0900 | 244€ |
|  | R | 1300 | 245€ |

Rooms in the School of Engineering were grouped into categories based on similar capacities, equipment, and their location within the school building. Table 2 shows the room group index number and the actual room numbers that correspond to the grouping.

**Table 2.  Room Groups**

| Room Group | Classroom Numbers | Capacity |
|:---:|:---:|:---:|
| 1 | 60,62€ | 35€ |
| 2 | 160-163€ | 30€ |
| 3 | 260-263€ | 28€ |
| 4 | 172, 176B€ | 35&24€ |
| 5 | 64A,164A,176A€ | 10€ |
| 6 | Labs 241,265,121€ | 25€ |
| 7 | Lecture Hall 121€ | 54€ |
| 8 | Lecture Hall 230€ | 54€ |
| 9 | Computer Lab 165€ | 16€ |

**Solicitation of Preferences**

An electronic questionnaire, which took the instructor through a step by step process, was provided to the instructor of each course, lab and lecture to be scheduled. The questionnaire elicits a first, second and third choice for day/time preferences. The instructors chose a set of days of the week and a time range on those days for the start of their course or courses for each of the three preferences. The time ranges corresponded to five periods within the day. Table 4 shows the ranges and the corresponding start times with that range. In every case, with the exception of MORN, the range contains two start times. These preferences were transformed into scenario index numbers defined in Table 2. For example, if an instructor chose MWF MIDM as a preference, scenarios

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127 and 128 are used as indicators of this preference. In effect, each instructor could chose up to six scenarios via the three preferences.

**Table 3.  Time Ranges**

| Course Start Time | Time€ Range€ |
|---|---|
| 0800 | MORN |
| 0900,1000 | MIDM |
| 1100,1200 | NOON |
| 1300,1400 | EAFT |
| 1500,1600 | LAFT |

In a similar fashion, the questionnaire provided three room group preferences. Additionally, instructors could provide days of the week and time ranges when teaching was of no value. These scenarios are known as non-preferences. This will be discussed further later. Finally, the instructors indicated what contribution the day/time scenario preference and room preference would have on the value of course index number by providing weights, $w_{jiD}$ and $w_{riD}$.

Each completed questionnaire provided 18 binary variables to the MIP, a combination of 6 scenarios and 3 room group preferences. For example, the variable x0011283 would describe a preference for course 001 of day/time scenario 128 and room group 3. The value of this variable would be determined using equation (14) and the single dimensional value function shown in Figure 5. This value becomes the cost coefficient of the objective function of the MIP.

**MIP Formulation**

Obviously, a maximization of an objective function made up of the variables produced from the questionnaires would produce a schedule with the greatest overall value. An objective function of this type is of the form of equation (14), which is an additive value function. The use of an additive value function as the objective function does not violate the assumptions of an MIP formulation.

Winston (1994: 53) states that a viable objective function must meet two criteria. First, "the contribution to the objective function from each decision variable must be proportional to the decision variable." The fact that the value function is additive and linear satisfies this criteria. Secondly, according to Winston (1994: 53), "the contribution to the objective function for any variable is independent of the values of the other decision variables." As stated in the VFT theoretical presentation, additive value functions require mutual preferential independence of the attributes on which value is evaluated.

Mutual preferential independence is shown for the each attribute $x_{ijk}$ in the following manner. The value of any day/time scenario $j$ and room group $k$ of course $i$ remains constant to the decision maker regardless of the preferences placed on other day/time scenarios and room groups by the remaining instructors. In other words the partition of day/time scenarios and room groups for course $i$ is preferentially independent of the remaining day/time scenarios and room groups for other courses.

However, a schedule that simply maximized the additive value function would most certainly violate one of the go/no-go criteria and therefore be reduced, via equation (15), to an overall value of zero. Therefore, the following MIP formulation restricts the

feasible region to schedules that do not violate the go/no-go criteria. This is done through the use of three distinct types of constraints.

The first set of constraints require that each course is scheduled against one and only one scenario and room combination. The number of these constraints is equal to the total number of courses being scheduled. This set of constraints may possibly produce an MIP that has no feasible solution. If every combination of preference variables violate the other go/no-go criteria then a feasible solution does not exist. To remedy this possibility, a dummy variable, whose contribution to the objective function is zero, is included in this constraint. The dummy variable will, by definition, not violate any of the other constraints. The constraints become:

$$\sum_j \sum_k x_{ijk} + x_{id} = 1 \qquad \text{for all i} \qquad (16)$$

A second set of constraints insure that no student or instructor conflicts exist through the use of zoning constraints. Patterson and Albright (1975) used similar constraints in assembly line balancing problems. Zoning constraints preclude two sets of variables from using the same resource. Here zoning constraints prevent courses with common students or instructors from being scheduled, either in part or in whole, at simultaneous times on the same day(s). Variables whose course ID shares common students with course $i$ and whose scenario takes place across the same hour and day as any hour and day in scenario $j$ are included in the set $DECON_{ij}$. The zoning constraints then become:

$$M \cdot \sum_k x_{ijk} + \sum_{x_{ijk} \in DECON_{ij}} x_{ijk} \le M \qquad \text{for all i and j} \qquad (17)$$

where $M$ is a constant greater than the cardinality of $DECON_{ij}$. There are $i$ times $j$ number of constraints of this type.

The third set of constraints insure that the number of courses scheduled during any hour of the week in a room group does not exceed the number of rooms in that group. Variables whose room group includes $r$ and whose scenario occurs during time $t$ are included in the set $ROOM_{rt}$. $RMNUM_{rt}$ is a constant defined by the number of rooms in room group $r$ at time $t$. The constraints then become:

$$\sum_{x_{ijk} \in ROOM_{rt}} x_{ijk} \leq RMNUM_{rt} \qquad \text{for all } r \text{ and } t \qquad (18)$$

There are $r$ times $t$ constraints of this type.

The final MIP formulation maximizes the objective function subject to equations (16), (17), (18) and a restriction of the variables as binary. The full MIP formulation is shown below as problem P2.

**Problem P2:** MIP Formulation

Maximize $$\sum_i \sum_j \sum_k c_{ijk} \cdot x_{ijk}$$

Subject To

$$\sum_j \sum_k x_{ijk} + x_{id} = 1 \qquad \text{for all i}$$

$$M \cdot \sum_k x_{ijk} + \sum_{x_{ijk} \in DECON_{ij}} x_{ijk} \leq M \qquad \text{for all i and j}$$

$$\sum_{x_{ijk} \in ROOM_{rt}} x_{ijk} \leq RMNUM_{rt} \qquad \text{for all r and t}$$

$$x_{ijk} = \{0,1\} \qquad\qquad \text{for all i, j, and k}$$

If an instructor fails to provide three preferences for either day/time or room, the scheduler may assign neutral scenario and room preferences to generate variables associated with the course. The neutral scenarios and neutral rooms have a lower value than any of the three preferences (Refer to Figure 5). Moreover, neutral variables are assigned to any course whose dummy variable is chosen in the solution to P2. The scheduler chooses neutral scenarios from the set of possible scenarios minus preferred scenarios and non-preferred scenarios. Problem P2 can be solved in an iterative fashion until no dummy variables are selected, given a feasible schedule exists. A solution to P2 will provide the schedule with the best overall value for the preferences provided and the neutral variables chosen.

**Decision Support System**

In conjunction with a main goal of this research, a Decision Support System (DSS) makes implementation of Problem P2 virtually seamless. The Educational Decision Support and Scheduling System (EDSSS) is comprised of three parts: (1) an electronic questionnaire, (2) a problem generator, and (3) the Optimization Subroutine Library (OSL), an IBM MIP solver.

The electronic questionnaire is a menu driven Visual Basic Module run in MS Excel, that can be delivered via E-mail. The module displays a Windows dialogue box through which instructors indicate preferences and non-preferences for days and times as well as preferences for room groups. The questionnaire also solicits the respective

weighting for day/times and room groups.  Dropdown menus, containing available days, times and room groups, provide a user-friendly environment for preference selection.

The problem generator is an MS Excel spreadsheet, and uses a suite of modules programmed in Visual Basic.  Preferences, obtained via the electronic questionnaire, are arranged into a value table within the problem generator.  A course listing, containing the SSN of all students enrolled in each course, is automatically transformed into a course confliction matrix.  The course confliction matrix is a square matrix whose rows and columns are made up of the course listing.  Element [i,j] equals 1 if course i and course j possess a common student, and 0 otherwise.  Similarly, a scenario confliction matrix is a square matrix whose rows and columns are made up of the scenario list.  Element [i,j] of the scenario confliction matrix is 1 if scenario i and scenario j share any common hour on any matching day, and 0 otherwise.

The problem generator automatically generates the $DECON_{ij}$ and $ROOM_{rt}$ sets. Problem P2 is then generated in Mathematical Programming System (MPS) format.  The MPS formulation is transferred to OSL and solved as a maximization MIP.  OSL returns the $x_{ijk}$ variables whose value is 1 and a schedule is created.  If any dummy variables are returned then new neutral variables are entered into the generator value table and the process is rerun.

## RESULTS

The results presented are for the spring quarter at the School of Engineering for AFIT.  The spring quarter contains 83 different courses, labs, and group lectures.  The school building is divided into the 9 room groups shown in Table 2.  The instructors for each course, lab or lecture were given the opportunity to provide preferences for

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day/times and rooms. If an instructor is assigned to teach more than one course, lab or lecture, then multiple questionnaires were filled out and preferences were captured for each course. If an instructor did not wish to provide any preferences or did not completely fill out the questionnaire, then neutral preferences were assigned to the instructor by the scheduler. Implementation of Problem P2 for the spring quarter utilizes 1398 binary variables and 953 constraints.

Four different schedules were created. The schedules differed by the weighting assigned to each department, $w_D$. Therefore, only the cost coefficients of the objective function change. The variation in schedules provides the decision maker with a sensitivity of the departmental weighting on the overall value of the schedule, the number of 1st day/time preferences accommodated, and the number of neutral preferences assigned. These measures are considered to provide the most insight into the quality of a schedule. The number of 1st day/time preferences is used, in lieu of room preferences, because the overwhelming majority of instructors gave day/time preferences more weight.

The initial schedule uses an equal weighting for each department. The second schedule's departmental weighting is the percent of courses taught by that department of the total 83 offered by the school. This weighting potentially gives each course equal impact on the overall value. However, if department heads wish to weight a subset of their courses higher than the remaining courses in the department to reward the instructors with a greater opportunity of achieving first preferences, the remaining courses impact are less than the impact of courses whose department weighted all courses equally. The third schedule uses weighting commensurate with the number of students

the courses within that department instruct. The final variation combines the weighting used in the second schedule, however, all group lectures are given their first day/time preference. Table 4 shows the weights used for each scheduling variation.

**Table 4. Departmental Weightings**

| Schedule Weighting | Departments | | | | | |
|---|---|---|---|---|---|---|
| | ENC | ENG | ENP | ENS | ENV | ENY |
| Equal | 0.167 | 0.167 | 0.167 | 0.167 | 0.167 | 0.167 |
| Number of Courses | 0.145 | 0.349 | 0.205 | 0.108 | 0.06 | 0.133 |
| Number of Students | 0.128 | 0.391 | 0.203 | 0.149 | 0.047 | 0.082 |
| Number of Courses with Lectures Given | 0.145 | 0.349 | 0.205 | 0.108 | 0.06 | 0.133 |

Table 5 summarizes the problem generator time, OSL solver time and number of course not scheduled, i.e. assigned a dummy variable. The problem generator and OSL were run on a 200 MHz PC platform using WindowsNT.

**Table 5. Summary of Processing Times**

| Schedule Weighting | Problem Generator CPU Time (sec) | OSL Solver CPU Time (sec) | Number of Courses Not Scheduled |
|---|---|---|---|
| Equal | 580 | 1121 | 4 |
| Number of Courses | 619 | 1197 | 4 |
| Number of Students | 575 | 1073 | 3 |
| Number of Courses with Lectures Given | 620 | 798 | 4 |

Table 5 clearly shows that each schedule took less than 30 minutes to generate on a personal computer. The relatively short processing time will allow the scheduler to make new runs if enrollment data changes or instructors are reassigned to different courses. Additionally, any subsequent sensitivity analysis important to the decision maker can be readily provided.

The percentage of courses not scheduled, based on the preference variables, is less than 5% for any of the four schedules. The scheduler can assign new neutral preferences to these courses and rerun the process or, manually schedule the relatively small number of courses that remain unscheduled.

Figure 6 compares the overall value, whose range is 0 to 1, of the four scheduling variations. Clearly, the overall value is very insensitive to the departmental weighting.
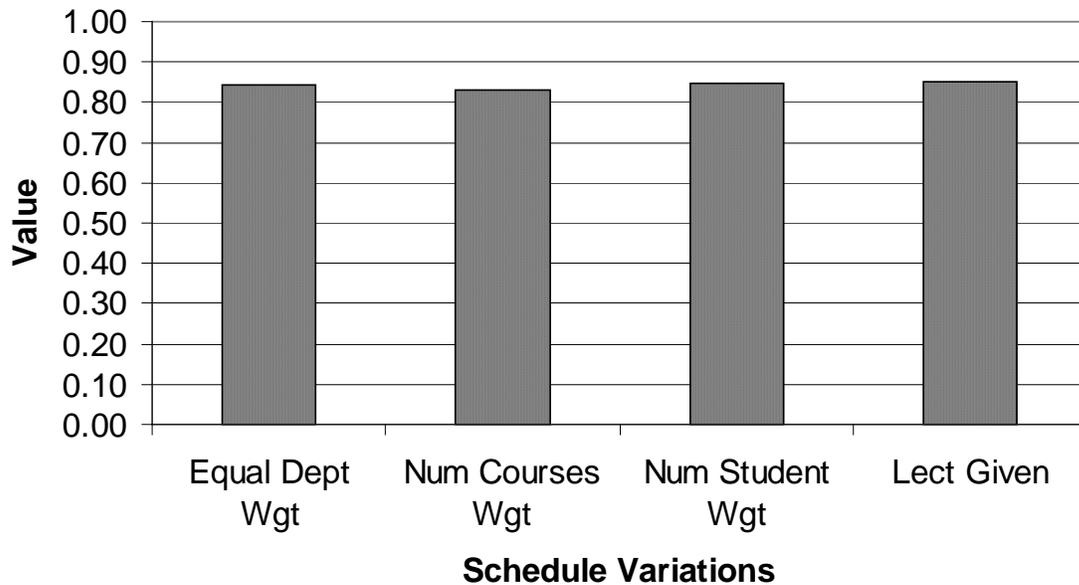


**Figure 6.  Overall Value of Schedules**

Figure 7 shows the value of each department for the four different departmental weightings.
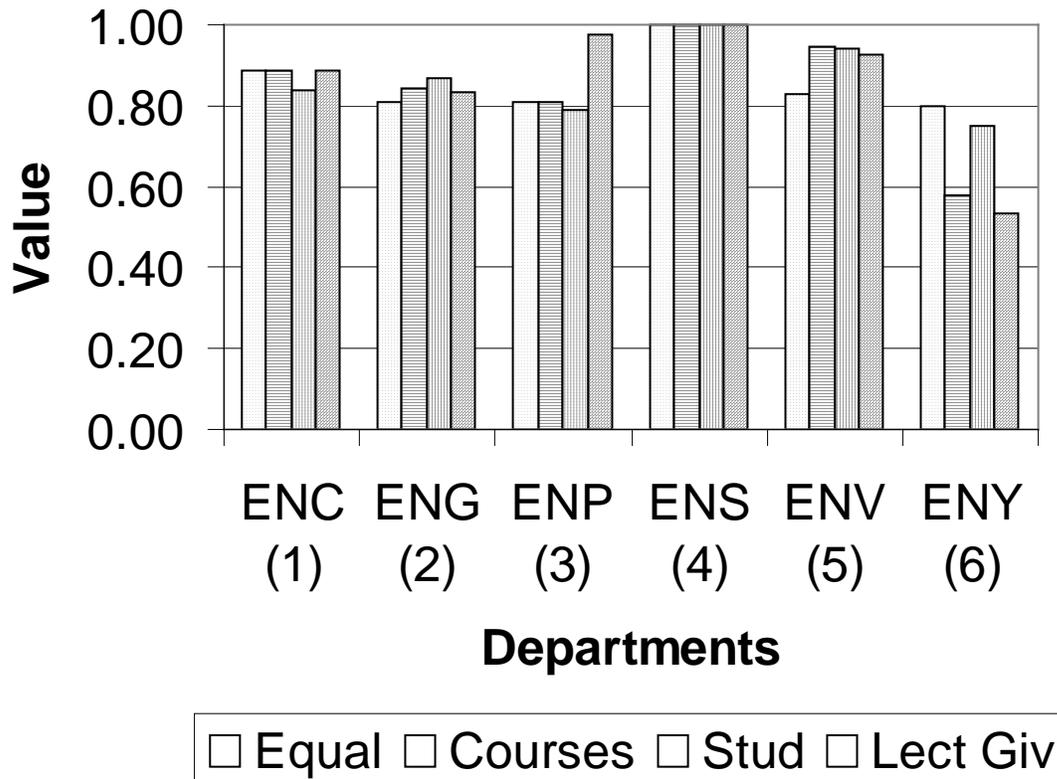


**Figure 7.  Departmental Value of Schedules**

The value of ENY shows the most sensitivity to departmental weighting.  However, the change in value is still relatively small, amounting to only 0.23 difference from highest value achieved with the equal weighting schedule and the lowest value when the departmental weighting is based upon number of courses.  Other departments indicate even less sensitivity to departmental weighting.

Another measure important to the decision maker is the amount of courses whose 1st day/time preference is accommodated. Figure 8 reveals the extent to which 1st day/time preferences were achieve for each department.
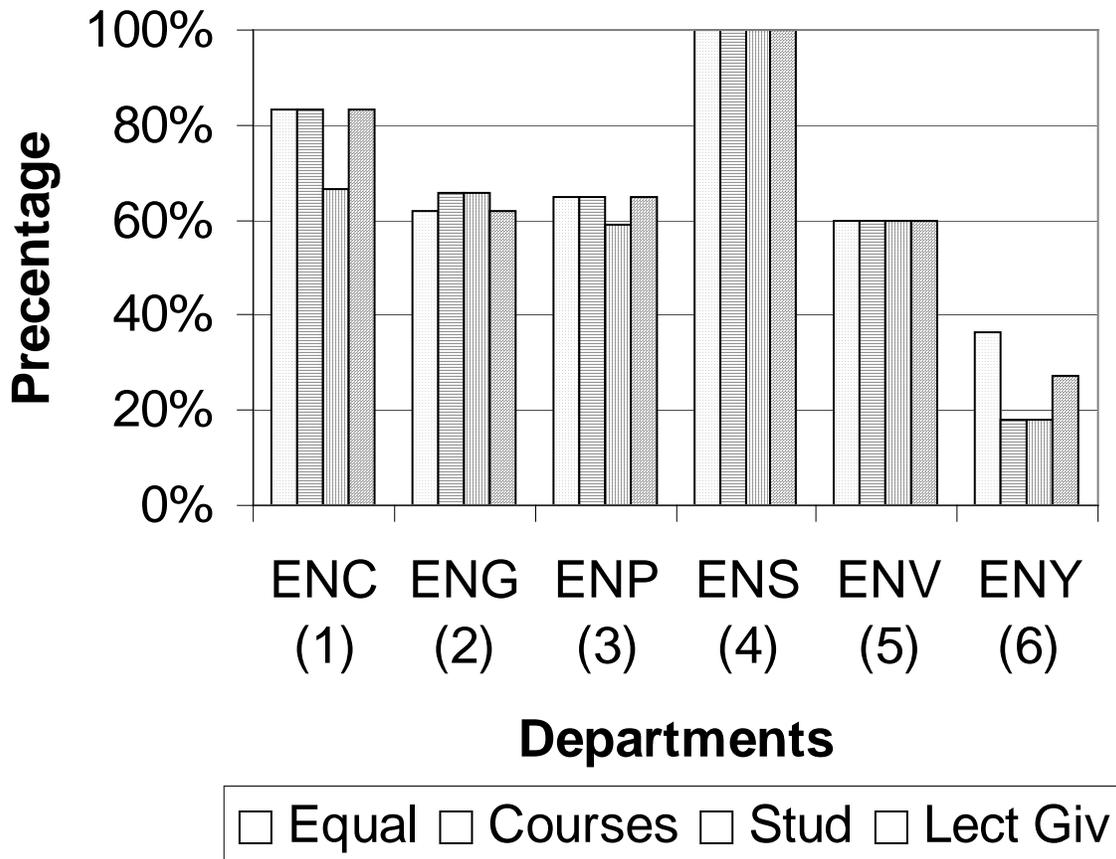


**Figure 8. Percentage of 1st Day/Time Preferences Accommodated**

In most cases, the number of 1st preferences given is from 60% - 100%. The exception is ENY. Again, little sensitivity is shown to the departmental weighting used to create the schedule. Figure 9 gives some insight to why departments such as ENS have a higher value and number of 1st preferences accommodated than other departments, such as ENY.
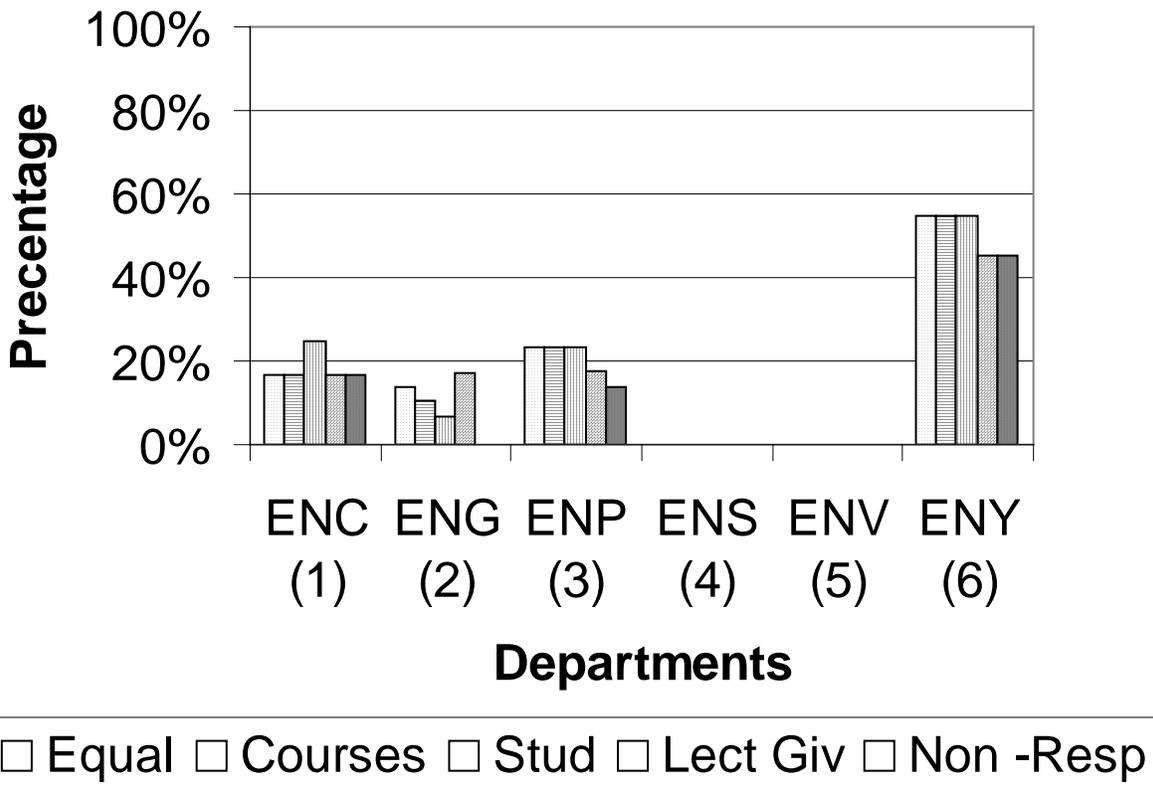
**Figure 9. Comparison of Neutral Day/Time Assignments to Non-Respondents**

Figure 9 shows a clear trend. The number of neutral day/time scenarios scheduled is proportionate to the number of instructors who did not provide any preferences. Neutral day/times are of significantly less value than any of the three preferred day/times and therefore contribute to a lower departmental value. Additionally, if no preferences are provided, 1st preferences cannot be accommodated.

**Iterative Approach to a Complete Schedule**

In each case, the schedules developed did not achieve a complete working schedule. The scheduling variation based upon departmental weighting proportionate to the number of course taught was chosen for completion. This variation was chosen because is provides the opportunity for equal weighting of all courses throughout the school.

The initial schedule did not schedule 4 courses, because the preferences associated with these course violated one of the go/no-go criteria. Therefore, preferences of these four instructors were changed to neutral preferences by the scheduler. Two additional iterations were required before a completed schedule was achieved. The overall value of this schedule was equal to .84, slightly higher than the original overall value. The completed schedule can be used to show room utilization throughout the school building. Figure 10, shows the utilization of classrooms, room groups 1-5.
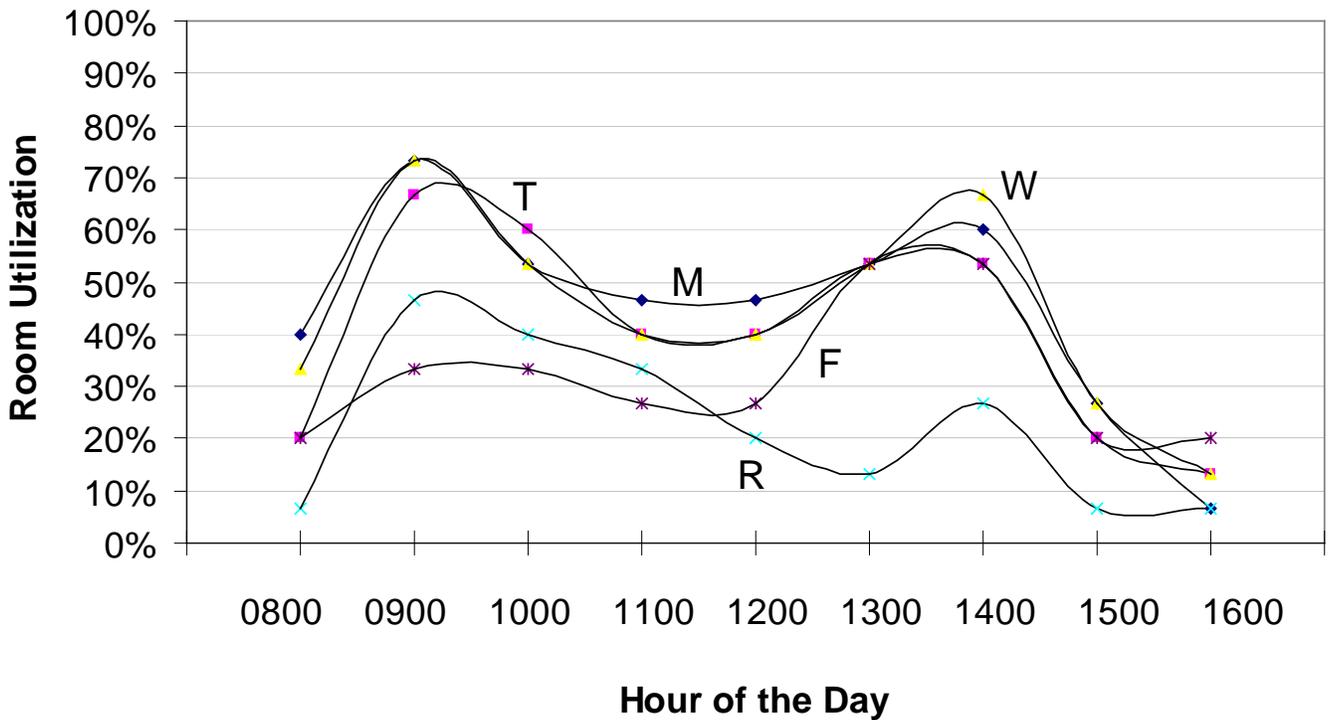


**Figure 10. Classroom Utilization for Completed Schedule**

Room utilization peaks at the most popular times of day, midmorning and early afternoon. However, room utilization levels during these popular times do not approach 100%. Therefore, any difficulty in scheduling 1st preferences must result from student or instructor conflicts.

## Conclusions

The research presented in this paper addresses four significant goals for academic course scheduling at the School of Engineering for AFIT. The important factors or values effecting the quality of an academic course schedule for the School of Engineering are identified. Metrics are established that measure how well a schedule addresses these values. A Decision Support System enables the Office of Academic Operations to implement the research and solicit individual preference efficiently. Finally, the research provides an expedient means of solving the academic course scheduling problem for the School of Engineering. The MIP formulation utilizes only a relatively small number of binary variables, allowing an initial solution in less than 30 minutes and a complete working schedule was achieved in less than 2 hours.

Moreover, the benefits of this research are not lost on larger institutions, for which Problem P2 becomes computationally inefficient to solve optimally. Heuristic solutions, using tabu or other search criteria, readily solve MIPs such as Problem P2, achieving working schedules representative of the institution's goals and principles.

Value Focused Thinking enabled the decision maker to decompose a difficult, complex problem into a simple set of values. These values are used to create alternatives and solve the difficult problem. The academic course scheduling problem at the School

of Engineering for AFIT is solved in a manner that maximizes the contribution the schedule makes to the institutes values and principles. Clearly, the ability of Decision Analysis and VFT as a viable technique to tackle the academic course scheduling problem and find a solution is validated.

# Chapter 3

Now that the EDSSS has been used to develop a schedule for the School of Engineering, an obvious extension to this research would create a working schedule for the entire Air Force Institute of Technology.  This would require the solicitation of preferences for both the School of Engineering and the School of Logistics.  The larger problem would give insight into the upper bound of courses that can be solved using a Mixed Integer Solver.

Additionally, other military institutions such as the Air Force Academy in Colorado Springs or the Military or Naval academies may provide an excellent source for application of this approach.  However, this approach is equally applicable to civilian institutions that wish to efficiently create an academic course schedule representative of the values of the varying stakeholders in the academic community.

A second area for extension would be to create a heuristic algorithm that can be incorporated in the existing EDSSS framework.  A quick heuristic solver incorporated into EDSSS would alleviate the requirement for an external Mixed Integer Solver.  A self-contained scheduling system would allow the simultaneous creation of multiple schedules on different PCs.

The final recommendation would determine the effect student day/time preferences have on the creation of a schedule.  Many civilian institutions may be less concerned with obtaining a completely deconflicted schedule, but rather wish to accommodate the

majority of students' time/day preferences.  Intercollegiate athletic practice, part-time or

full-time jobs, and so forth, may make certain day/time scenarios more or less attractive.

# Appendix A

# Complete 1998 Spring Quarter Schedule

Below is the completed schedule, assigning all courses to days, times and room group. Individual rooms within each group may be assigned arbitrarily or by departmental policy.

| | Course | | Instructor | Days | Times | Room Groups |
|---|---|---|---|---|---|---|
| MATH | 508 | 01 | BAKER | MTWR | 0900-1000 | 2 |
| MATH | 521 | 01 | WOOD | MTWF | 0800-0900 | 5 |
| MATH | 633 | 01 | LAIR | MTWF | 1300-1400 | 2 |
| MATH | 674 | 01 | CHILTON | MTWR | 0900-1000 | 2 |
| MATH | 705 | 01 | OXLEY | MWRF | 0900-1000 | 5 |
| STAT | 528 | 01 | REYNOLDS | MWF | 1600-1700 | 3 |
| STAT | 528 | 01 | REYNOLDS | T | 0800-1000 | 9 |
| STAT | 583 | 91 | CROWN | MTWF | 0900-1000 | 5 |
| STAT | 696 | 01 | CROWN | TWF | 1300-1400 | 2 |
| STAT | 696 | 91 | CROWN | T | 1400-1600 | 9 |
| STAT | 696 | 02 | REID | MWF | 1300-1400 | 2 |
| STAT | 696 | 92 | REID | T | 1000-1200 | 9 |
| | | | | | | |
| CSCE | 532 | 01 | POTOCZNY | MW | 1200-1400 | 2 |
| CSCE | 544 | 01 | POTOCZNY | TF | 1000-1200 | 4 |
| CSCE | 595 | 01 | GRAHAM | TF | 1400-1600 | 2 |
| CSCE | 595 | 91 | GRAHAM | R | 1300-1600 | 6 |
| CSCE | 623 | 01 | BANKS | MW | 1400-1600 | 3 |
| CSCE | 646 | 01 | TALBERT | TF | 1200-1400 | 3 |
| CSCE | 654 | 01 | RAINES | MW | 1400-1600 | 2 |
| CSCE | 656 | 01 | LAMONT | TF | 1200-1400 | 3 |
| CSCE | 682 | 01 | STYTZ | TWRF | 1600-1700 | 5 |
| CSCE | 683 | 01 | SHOMPER | TF | 1400-1600 | 5 |
| CSCE | 686 | 01 | LAMONT | MTRF | 0800-0900 | 4 |
| CSCE | 698 | 01 | RAINES | R | 1000-1100 | 7 |
| CSCE | 793 | 01 | HARTRUM | MW | 1000-1200 | 4 |
| CSCE | 793 | 91 | HARTRUM | R | 1100-1200 | 8 |
| EENG | 533 | 01 | MILLER | MW | 1000-1200 | 3 |
| EENG | 533 | 91 | MILLER | R | 1300-1500 | 6 |
| EENG | 621 | 01 | GUFESTAFSEN | MW | 1200-1400 | 5 |
| EENG | 625 | 01 | TERZUOLI | MTWF | 1600-1700 | 6 |
| EENG | 629 | 01 | PYATI | MTWF | 0900-1000 | 5 |
| EENG | 630 | 01 | COLLINS | MTWF | 1400-1500 | 4 |
| EENG | 635 | 01 | LEWANTOWICZ | TR | 1000-1200 | |
| EENG | 640 | 01 | PATCHER | TF | 1100-1300 | 3 |
| EENG | 670 | 01 | TEMPLE | TF | 1200-1400 | 3 |
| EENG | 695 | 01 | GELOSH | TF | 1300-1500 | 3 |
| EENG | 695 | 91 | GELOSH | R | 1300-1600 | 6 |
| EENG | 698 | 01 | TEMPLE | R | 1000-1100 | 8 |
| EENG | 700 | 01 | TERZUOLI | R | 1200-1300 | 6 |
| EENG | 708 | 01 | PATCHER | MW | 1200-1400 | 3 |
| EENG | 766 | 01 | MAYBECK | TF | 0900-1100 | 5 |

| CHEM | 585 | 01 | BURGGRAF | MTRF | 1000-1100 | 4 |
|------|-----|-----|----------|------|-----------|---|
| CHEM | 675 | 01 | WOLF | MTWF | 1400-1500 | 5 |
| EVSC | 560 | 01 | BURGGRAF | MTRF | 1100-1200 | 1 |
| EVSC | 670 | 01 | MATHEWS | TWRF | 1400-1500 | 5 |
| METG | 630 | 01 | ASKUE | M | 1300-1500 | 3 |
| METG | 630 | 91 | ASKUE | TR | 1300-1600 | 9 |
| METG | 642 | 01 | DUNGEY | MTWR | 1200-1300 | 2 |
| METG | 798 | 01 | DUNGEY | W | 1500-1600 | 7 |
| NENG | 560 | 01 | SUSALLA | MW | 1000-1200 | 5 |
| NENG | 631 | 01 | SUSALLA | TR | 0900-1100 | 5 |
| OENG | 620 | 01 | ROH | MTWF | 0900-1000 | 2 |
| OENG | 650 | 01 | HENGEHOLD | TWRF | 1100-1200 | 1 |
| PHYS | 519 | 01 | GOLDIZEN | MTWF | 1000-1100 | 2 |
| PHYS | 542 | 01 | ROH | MWF | 1400-1500 | 2 |
| PHYS | 542 | 91 | ROH | R | 1300-1600 | 2 |
| PHYS | 650 | 01 | BAILEY | MTWR | 1000-1100 | 2 |
| PHYS | 798 | 01 | LARGENT | M | 1300-1400 | 8 |

| OPER | 403 | 01 | MILLER | R | 1300-1500 | 7 |
|------|-----|-----|----------|------|-----------|---|
| OPER | 561 | 01 | BAUER | TR | 1100-1300 | 4 |
| OPER | 561 | 02 | BAILEY | MW | 1000-1200 | 4 |
| OPER | 561 | 03 | MILLER | MW | 0900-1100 | 1 |
| OPER | 601 | 01 | DECKRO | R | 0900-1000 | 5 |
| OPER | 610 | 01 | CHAN | TWRF | 1000-1100 | 5 |
| OPER | 610 | 02 | CHRISSIS | MW | 1400-1600 | 4 |
| OPER | 610 | 03 | MOORE | MW | 1400-1600 | 4 |
| OPER | 645 | 01 | KLOBER | MW | 0800-1000 | 4 |

| EMGT | 571 | 01 | GILL | MW | 1200-1400 | 1 |
|------|-----|-----|----------|------|-----------|---|
| ENVR | 503 | 01 | LOFGREN | T | 0900-1000 | 2 |
| ENVR | 535 | 01 | NIXON | TR | 1300-1500 | 3 |
| ENVR | 621 | 01 | SHELLEY | TR | 0900-1100 | 3 |
| ENVR | 623 | 01 | BLECKMAN | MW | 0800-1000 | 3 |

| MECH | 533 | 01 | AGNES | MWF | 1400-1500 | 3 |
|------|-----|-----|----------|------|-----------|---|
| MECH | 605 | 01 | PALAZOTTO | TR | 1100-1300 | 5 |
| MECH | 620 | 01 | POHL | MW | 0800-1000 | 5 |
| MECH | 628 | 01 | LIEBST | TF | 1500-1700 | 4 |
| MECH | 636 | 01 | WIESEL | MW | 1100-1300 | 1 |
| MECH | 642 | 01 | TURCOTTE | MTWF | 1000-1100 | 3 |
| MECH | 723 | 01 | SPENNY | MTWF | 0800-0900 | 2 |
| MENG | 531 | 01 | LITTLE | MTWF | 1300-1400 | 3 |
| MENG | 732 | 01 | KING | TWRF | 1400-1500 | 3 |
| SENG | 535 | 01 | KRAMER | R | 0900-1200 | 6 |
| SENG | 665 | 01 | HEISE | MTWR | 0900-1000 | 3 |

# Appendix B

# Electronic Questionnaire Source Code

This appendix contains the visual basic modules used to generate the electronic questionnaire used by EDSSS to capture faculty day/time preferences and non-preferences, as well as room group preferences. The modules were written in MS Excel 97.

```
'This subroutine hides specific worksheets when file is opened

Sub Auto_Open()
    Worksheets("Data").Visible = False
    DialogSheets("dlgFacultyInput").Visible = False
    DialogSheets("dlgPref1").Visible = False
    DialogSheets("dlgPref2").Visible = False
    DialogSheets("dlgPref3").Visible = False
    DialogSheets("dlgPref4").Visible = False
    DialogSheets("dlgInstr1").Visible = False
    DialogSheets("dlgInstr2").Visible = False
    DialogSheets("dlgInstr3").Visible = False
    DialogSheets("dlgInstr4").Visible = False
    DialogSheets("dlgThanks").Visible = False
    Modules("modQuest").Visible = False
End Sub

'This subroutine displays hidden worksheeets

Sub UnHide()
    Worksheets("Data").Visible = True
    DialogSheets("dlgFacultyInput").Visible = True
    DialogSheets("dlgPref1").Visible = True
    DialogSheets("dlgPref2").Visible = True
    DialogSheets("dlgPref3").Visible = True
    DialogSheets("dlgPref4").Visible = True
    DialogSheets("dlgInstr1").Visible = True
    DialogSheets("dlgInstr2").Visible = True
    DialogSheets("dlgInstr3").Visible = True
```

```vba
      DialogSheets("dlgInstr4").Visible = True
      DialogSheets("dlgThanks").Visible = True
      Modules("modQuest").Visible = True
End Sub


'This subroutine shows the instructions dialogue box

Sub ShowInstructions()
   If DialogSheets("dlgInstr1").Show = True Then
      If DialogSheets("dlgInstr2").Show = True Then
         If DialogSheets("dlgInstr3").Show = True Then
            DialogSheets("dlgInstr4").Show
         End If
      End If
   End If
End Sub


'This subroutine shows the preferences dialogue box and captures the inputs by the user

Sub ShowDialog()

   With DialogSheets("dlgFacultyInput")
      If .Show = True Then
         Instructor = .EditBoxes("txtInstructor").Text
         Course = .EditBoxes("txtCourse").Text
         Dept = .DropDowns("drpDepartment").Value
         If .OptionButtons("optHour1").Value = 1 Then
               With DialogSheets("dlgPref1")
                  If .Show = True Then
                        hrPerWeek = 1
                        daysP1 = .DropDowns("drpDaysP1").Value
                        daysP2 = .DropDowns("drpDaysP2").Value
                        daysP3 = .DropDowns("drpDaysP3").Value
                        daysNP1 = .DropDowns("drpDaysNP1").Value
                        daysNP2 = .DropDowns("drpDaysNP2").Value
                        daysNP3 = .DropDowns("drpDaysNP3").Value
                        timeP1 = .DropDowns("drpTimesP1").Value
                        timeP2 = .DropDowns("drpTimesP2").Value
                        timeP3 = .DropDowns("drpTimesP3").Value
                        timeNP1 = .DropDowns("drpTimesNP1").Value
                        timeNP2 = .DropDowns("drpTimesNP2").Value
                        timeNP3 = .DropDowns("drpTimesNP3").Value
                        roomP1 = .DropDowns("drpRoomsP1").Value
                        roomP2 = .DropDowns("drpRoomsP2").Value
                        roomP3 = .DropDowns("drpRoomsP3").Value
                        dayWgt = .EditBoxes("txtDayWgt").Text
                        feedbck = .EditBoxes("txtComments").Text
                        DialogSheets("dlgThanks").Show
                  Else
                        Worksheets("INTERFACE").Activate
                  End If
               End With
         End If
         If .OptionButtons("optHour2").Value = 1 Then
               With DialogSheets("dlgPref2")
                  If .Show = True Then
```

```
                hrPerWeek = 2
                daysP1 = .DropDowns("drpDaysP1").Value
                daysP2 = .DropDowns("drpDaysP2").Value
                daysP3 = .DropDowns("drpDaysP3").Value
                daysNP1 = .DropDowns("drpDaysNP1").Value
                daysNP2 = .DropDowns("drpDaysNP2").Value
                daysNP3 = .DropDowns("drpDaysNP3").Value
                timeP1 = .DropDowns("drpTimesP1").Value
                timeP2 = .DropDowns("drpTimesP2").Value
                timeP3 = .DropDowns("drpTimesP3").Value
                timeNP1 = .DropDowns("drpTimesNP1").Value
                timeNP2 = .DropDowns("drpTimesNP2").Value
                timeNP3 = .DropDowns("drpTimesNP3").Value
                roomP1 = .DropDowns("drpRoomsP1").Value
                roomP2 = .DropDowns("drpRoomsP2").Value
                roomP3 = .DropDowns("drpRoomsP3").Value
                dayWgt = .EditBoxes("txtDayWgt").Text
                feedbck = .EditBoxes("txtComments").Text
                DialogSheets("dlgThanks").Show
        Else
                Worksheets("INTERFACE").Activate
        End If
    End With
End If
If .OptionButtons("optHour3").Value = 1 Then
    With DialogSheets("dlgPref3")
        If .Show = True Then
                hrPerWeek = 3
                daysP1 = .DropDowns("drpDaysP1").Value
                daysP2 = .DropDowns("drpDaysP2").Value
                daysP3 = .DropDowns("drpDaysP3").Value
                daysNP1 = .DropDowns("drpDaysNP1").Value
                daysNP2 = .DropDowns("drpDaysNP2").Value
                daysNP3 = .DropDowns("drpDaysNP3").Value
                timeP1 = .DropDowns("drpTimesP1").Value
                timeP2 = .DropDowns("drpTimesP2").Value
                timeP3 = .DropDowns("drpTimesP3").Value
                timeNP1 = .DropDowns("drpTimesNP1").Value
                timeNP2 = .DropDowns("drpTimesNP2").Value
                timeNP3 = .DropDowns("drpTimesNP3").Value
                roomP1 = .DropDowns("drpRoomsP1").Value
                roomP2 = .DropDowns("drpRoomsP2").Value
                roomP3 = .DropDowns("drpRoomsP3").Value
                dayWgt = .EditBoxes("txtDayWgt").Text
                feedbck = .EditBoxes("txtComments").Text
                DialogSheets("dlgThanks").Show
        Else
                Worksheets("INTERFACE").Activate
        End If
    End With
End If
If .OptionButtons("optHour4").Value = 1 Then
    With DialogSheets("dlgPref4")
        If .Show = True Then
                hrPerWeek = 4
                daysP1 = .DropDowns("drpDaysP1").Value
```

```
                        daysP2 = .DropDowns("drpDaysP2").Value
                        daysP3 = .DropDowns("drpDaysP3").Value
                        daysNP1 = .DropDowns("drpDaysNP1").Value
                        daysNP2 = .DropDowns("drpDaysNP2").Value
                        daysNP3 = .DropDowns("drpDaysNP3").Value
                        timeP1 = .DropDowns("drpTimesP1").Value
                        timeP2 = .DropDowns("drpTimesP2").Value
                        timeP3 = .DropDowns("drpTimesP3").Value
                        timeNP1 = .DropDowns("drpTimesNP1").Value
                        timeNP2 = .DropDowns("drpTimesNP2").Value
                        timeNP3 = .DropDowns("drpTimesNP3").Value
                        roomP1 = .DropDowns("drpRoomsP1").Value
                        roomP2 = .DropDowns("drpRoomsP2").Value
                        roomP3 = .DropDowns("drpRoomsP3").Value
                        dayWgt = .EditBoxes("txtDayWgt").Text
                        feedbck = .EditBoxes("txtComments").Text
                        DialogSheets("dlgThanks").Show
                Else
                        Worksheets("INTERFACE").Activate
                End If
            End With
        End If


        Worksheets("DATA").Cells(3, 1).Value = Instructor
        Worksheets("DATA").Cells(3, 2).Value = Course
        Worksheets("DATA").Cells(3, 3).Value = Dept
        Worksheets("DATA").Cells(3, 4).Value = hrPerWeek
        Worksheets("DATA").Cells(3, 5).Value = dayWgt
        Worksheets("DATA").Cells(3, 6).Value = 1 - Val(dayWgt)
        Worksheets("DATA").Cells(3, 7).Value = daysP1
        Worksheets("DATA").Cells(3, 8).Value = timeP1
        Worksheets("DATA").Cells(3, 9).Value = roomP1
        Worksheets("DATA").Cells(3, 10).Value = daysP2
        Worksheets("DATA").Cells(3, 11).Value = timeP2
        Worksheets("DATA").Cells(3, 12).Value = roomP2
        Worksheets("DATA").Cells(3, 13).Value = daysP3
        Worksheets("DATA").Cells(3, 14).Value = timeP3
        Worksheets("DATA").Cells(3, 15).Value = roomP3
        Worksheets("DATA").Cells(3, 16).Value = daysNP1
        Worksheets("DATA").Cells(3, 17).Value = timeNP1
        Worksheets("DATA").Cells(3, 18).Value = daysNP2
        Worksheets("DATA").Cells(3, 19).Value = timeNP2
        Worksheets("DATA").Cells(3, 20).Value = daysNP3
        Worksheets("DATA").Cells(3, 21).Value = timeNP3
        Worksheets("DATA").Cells(3, 22).Value = feedbck
    End If
  End With
End Sub
```

# Appendix C

# Problem Generator Source Code

This appendix contains the visual basic modules used in the problem generator portion of  EDSSS to write the Mixed Integer Program shown by Problem P2 in Mathematical Programming System (MPS) format.  The modules were written in MS Excel 97.

```
'This subroutine hides specific spreadsheets when the document is opened

Sub AutoOpen()
   ThisWorkbook.Activate
   With ActiveWorkbook
      Worksheets(2).Visible = False
      Worksheets(3).Visible = False
      Worksheets(4).Visible = False
      Worksheets(5).Visible = False
      Worksheets(6).Visible = False
      Worksheets(7).Visible = False
   End With
End Sub

'This subroutine unhides the spreadsheets hidden upon opening

Sub UnHide()
   ThisWorkbook.Activate
   With ActiveWorkbook
      Worksheets(2).Visible = True
      Worksheets(3).Visible = True
      Worksheets(4).Visible = True
      Worksheets(5).Visible = True
      Worksheets(6).Visible = True
      Worksheets(7).Visible = True
   End With
End Sub
```

'This subroutine is the main routine and calls the other main routines in the
'correct order

```vba
Sub Schedule()
    MsgBox (Now())
    Call EdPlans
    Call Variables
    Call WriteMps
    MsgBox (Now())
End Sub
```
'This subroutine puts the Value table into the correct format for
'processing.

```vba
Sub FormatTable()
    Worksheets("Vbl Def").Select
    With ActiveSheet
        Set eeRange = Range("M1:R83")
        For Each C In eeRange
            If C.Value <> "" Then
                If Len(LTrim(Str(C.Value))) = 1 Then C.Value = "00" & LTrim(Str(C.Value))
                If Len(LTrim(Str(C.Value))) = 2 Then C.Value = "0" & LTrim(Str(C.Value))
                If Len(LTrim(Str(C.Value))) = 3 Then C.Value = "" & LTrim(Str(C.Value))
            End If
            Next C
    End With
End Sub
```

'This subroutine writes all the variables in the variable list

```vba
Sub WriteVbls()
    Worksheets("Vbl Def").Select
    With ActiveSheet
        Set clearRange = Range("A1:G10000")
        clearRange.ClearContents
        clearRange.Font.Bold = False

        i = 1
        Do Until Cells(i, 10) = ""
            C = 1 + (i - 1) * 18
            Cells(C, 1).Value = Cells(i, 10).Value
            j = 1
            Do Until Cells(i, 12 + j) = "" Or j > 6
                d = C + (j - 1) * 3
                Cells(d, 2).Value = Cells(i, 12 + j).Value
                If Cells(i, 12 + j).Font.Bold = True Then
                    Cells(d, 2).Font.Bold = True
                End If
                k = 1
                Do Until Cells(i, 18 + k) = "" Or k > 3
                    e = d + k - 1
                    Cells(e, 4).Value = Cells(i, 18 + k).Value
                    If Cells(i, 18 + k).Font.Bold = True Then
                        Cells(e, 4).Font.Bold = True
                    End If
                    Cells(e, 6).Value = "x" & Cells(i, 10) & Cells(i, 12 + j) & Cells(i, 18 + k)
```

```
            k = k + 1
         Loop
         j = j + 1
       Loop
       i = i + 1
     Loop
   End With
End Sub

'Writes objective value for each variable

Sub PutValues()
   Worksheets("Vbl Def").Select
   With ActiveSheet
     i = 1
     j = 1
     Do While i < 10000 And j < 10000
        If Cells(i, 2) <> "" Then
           If Cells(i, 2).Font.Bold = True Then
              ScenValue = 0.333
           Else
              ScenValue = GetScenValue(i)
           End If
           Cells(i, 3).Value = ScenValue
           Cells(i + 1, 3).Value = ScenValue
           Cells(i + 2, 3).Value = ScenValue
           i = i + 3
        Else
           i = i + 3
        End If
        If Cells(j, 4) <> "" Then
           If Cells(j, 4).Font.Bold = True Then
              RoomValue = 0.333
           Else
              RoomValue = GetRoomValue(j)
           End If
           Cells(j, 5).Value = RoomValue
           j = j + 1
        Else
           j = j + 1
        End If
     Loop

     k = 1
     m = 1
     Do While k < 10000
        If Cells(k, 6) <> "" Then
           impact = (Cells(m, 11).Value * Cells(k, 3) + Cells(m, 12).Value * Cells(k, 5)) *
Cells(m, 22) * 100000
           Cells(k, 7).Value = Int(impact)
           k = k + 1
        Else
           k = k + 1
        End If
        If k Mod 18 = 1 Then m = m + 1
     Loop
```

```
        End With
End Sub

Function GetScenValue(vrow)
    p = vrow Mod 18
    If p = 1 Then GetScenValue = 1
    If p = 4 Then GetScenValue = 1
    If p = 7 Then GetScenValue = 0.833
    If p = 10 Then GetScenValue = 0.833
    If p = 13 Then GetScenValue = 0.667
    If p = 16 Then GetScenValue = 0.667
End Function

Function GetRoomValue(vrow)
    p = vrow Mod 18
    If p = 1 Then GetRoomValue = 1
    If p = 2 Then GetRoomValue = 0.833
    If p = 3 Then GetRoomValue = 0.667
    If p = 4 Then GetRoomValue = 1
    If p = 5 Then GetRoomValue = 0.833
    If p = 6 Then GetRoomValue = 0.667
    If p = 7 Then GetRoomValue = 1
    If p = 8 Then GetRoomValue = 0.833
    If p = 9 Then GetRoomValue = 0.667
    If p = 10 Then GetRoomValue = 1
    If p = 11 Then GetRoomValue = 0.833
    If p = 12 Then GetRoomValue = 0.667
    If p = 13 Then GetRoomValue = 1
    If p = 14 Then GetRoomValue = 0.833
    If p = 15 Then GetRoomValue = 0.667
    If p = 16 Then GetRoomValue = 1
    If p = 17 Then GetRoomValue = 0.833
    If p = 0 Then GetRoomValue = 0.667
End Function

'This subroutine puts the value list in the correct format

Sub FormatList()
    Worksheets("Vbl Def").Select
    With ActiveSheet
        Set ddRange = Range("A1:B10000")
        For Each C In ddRange
            If C.Value <> "" Then
                If Len(LTrim(Str(C.Value))) = 1 Then C.Value = "00" & LTrim(Str(C.Value))
                If Len(LTrim(Str(C.Value))) = 2 Then C.Value = "0" & LTrim(Str(C.Value))
                If Len(LTrim(Str(C.Value))) = 3 Then C.Value = "" & LTrim(Str(C.Value))
            End If
            Next C
    End With
End Sub

'Subroutine called by Schedule

Public Sub Variables()
    Call FormatTable
    Call WriteVbls
```

```
      Call PutValues
      Call FormatList
   End Sub

Dim mpsrow As Integer
 Dim conCourCol As Integer
 Dim conScenCol As Integer
 Dim mpsPath As String
 Dim mpsFileName As String

 Dim numvbls As Integer
 Dim numcourses As Integer
 Dim numscenarios As Integer
 Dim scenRange As Range
 Dim courRange As Range
 Dim vblCourRange As Range
 Dim vblScenRange As Range
 Dim vblRoomRange As Range
 Dim vblVblRange As Range

'Sets certain constants provided by the user on the "Code Data"
'spreadsheet

Sub GetConstants()
   numcourses = Sheets("Code Data").Cells(2, 3)
   numscenarios = Sheets("Code Data").Cells(3, 3)
   numvbls = Sheets("Code Data").Cells(5, 3)
   mpsPath = Worksheets("Code Data").Cells(6, 3)
   mpsFileName = Worksheets("Code Data").Cells(7, 3)
   Set scenRange = Worksheets("Scenario Confl").Range("A1:IV1")
   Set courRange = Worksheets("Course Confl").Range("A1:IV1")
   Set vblCourRange = Worksheets("Vbl Def").Range("A1:A1530")
   Set vblScenRange = Worksheets("Vbl Def").Range("B1:B1530")
   Set vblRoomRange = Worksheets("Vbl Def").Range("D1:D1530")
   Set vblVblRange = Worksheets("Vbl Def").Range("F1:F1520")
End Sub

'This subroutine opens the output file named schedmps.mps where
'the mps data will be written.

Sub OpenOutFile()
   mpsFile = mpsPath & mpsFileName
   Open mpsFile For Output As #9
   '       123456789012345678901235
   Print #9, "NAME          SchedMps  FREE"
   Print #9, "ROWS"
   Print #9, " N   obj"
End Sub

'This subroutine writes to schedmps the ROWS portion of the .mps file.
'Where:
'axpppij are the one assignment per course "ppp" constraints
'dxpppqqqi are the deconfliction constraints associated with course
'        "ppp" and time scenario "qqq"
'rhhg are the room resourse constraints associated with time slot
'        "hh" and room group "g"
```

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```
Sub WriteRows()

  Worksheets("Vbl Def").Select
  With ActiveSheet

    'Writes the single assignments rows
    i = 1
    Do Until i > numvbls
      If Cells(i, 6).Value = "" Then
        i = i + 18
      Else
        Print #9, " E    " & "a" & Left(Cells(i, 6), 4) & "ij"
        i = i + 18
      End If
    Loop

    'Writes the deconfliction rows
    j = 1
    Do Until j > numvbls
      If Cells(j, 6).Value = "" Then
        j = j + 3
      Else
        Print #9, " L    " & "d" & Left(Cells(j, 6), 7) & "i"
        j = j + 3
      End If
    Loop

    'Writes the room resourse rows, 45 time slots per week &
    '9 different room groups
    k = 1
    Do Until k > 45
      l = 1
      Do Until l > 9
        If Len(LTrim(Str(k))) = 1 Then
          timeslot = "0" & LTrim(Str(k))
        Else
          timeslot = LTrim(Str(k))
        End If
        Print #9, " L    " & "r" & timeslot & l
        l = l + 1
      Loop
      k = k + 1
    Loop

  End With
End Sub

'Retrieves the three digit scenario number "sss" from the variable
'of the type xccc,sss,r

Function IsolateScenario(variable)
  IsolateScenario = Mid(variable, 5, 3)
End Function

'Retrieves the three digit course number "ccc" from the variable
```

'of the type xccc,sss,r

```
Function IsolateCourse(variable)
   IsolateCourse = Mid(variable, 2, 3)
End Function
```

'Matches the current scenario with the same scenario on the
'"Scenario Confl" spreadsheet

```
Function ScenarioCol(scenario)
   If TypeName(scenRange.Find(scenario)) = "Range" Then
      ScenarioCol = scenRange.Find(scenario).column
   Else
      ScenarioCol = 9999
   End If
End Function
```

'Matches the current course with the same course on the
'"Course Confl" spreadsheet

```
Function CourseCol(courseNumber)
   If TypeName(courRange.Find(courseNumber)) = "Range" Then
      CourseCol = courRange.Find(courseNumber).column
   Else
      CourseCol = 9999
   End If
End Function
```

'Isolates a single Day from a string of Days

```
Function EachDay(days, x)
   EachDay = Mid(days, x, 1)
End Function
```

'Writes the Initial Columns for the .mps file

```
Sub InitialColumnEntry(ByVal variable, ByVal impact)
   Print #9, "    " & variable & "    obj" & "    " & impact
   Print #9, "    " & variable & "    a" & Left(variable, 4) & "ij" & "    1.0"
   Print #9, "    " & variable & "    d" & Left(variable, 7) & "i" & "    100.0"
End Sub
```

'Writes the deconfliction columns, i.e. any course and time to which
'the current variable is conflicted a 1.0 is placed in that column

```
Sub DeconColumnEntry(ByVal variable)
   Dim scenConflicts(1 To 100) As String
   Dim courConflicts(1 To 100) As String

   'Gets the scenario and course number for the variable
   courseNum = IsolateCourse(variable)
   scenario = IsolateScenario(variable)

   'Reads into an array all of the scenarios that conflict with
   'the current variable's scenario
   i = 3
```

```
    scencol = ScenarioCol(scenario)
    Do Until Worksheets("Scenario Confl").Cells(i, scencol).Value = ""
        scenConflicts(i) = Worksheets("Scenario Confl").Cells(i, scencol)
        i = i + 1
    Loop

    'Reads into an array all of the courses that conflict with the
    'current variable's course
    j = 3
    courCol = CourseCol(courseNum)
    Do Until Worksheets("Course Confl").Cells(j, courCol).Value = ""
        courConflicts(j) = Worksheets("Course Confl").Cells(j, courCol)
        j = j + 1
    Loop

    'Checks for both course confliction and scenario confliction
    'and writes the coulumn variable for the conflicted row if
    'both course and scenario are indeed conflicted

    Worksheets("Vbl Def").Select
    With ActiveSheet
    k = 1
    Do While k <= j - 1
        If TypeName(vblCourRange.Find(courConflicts(k))) = "Range" Then
            conCourrow = vblCourRange.Find(courConflicts(k)).row
            l = 1
            Do While l <= i
                endrow = conCourrow + 17
                z = conCourrow
                Do While z <= endrow And scenConflicts(l) <> ""
                    inside = i
                    If Cells(z, 2) = scenConflicts(l) Then
                        Print #9, "     " & variable & "      " & "d" & Left(Sheets("Vbl Def").Cells(z,
6).Value, 7) & "i" & "    1.0"
                        z = conCourrow + 20
                    Else
                        z = z + 3
                    End If
                Loop
                l = l + 1
            Loop
        End If
        k = k + 1
    Loop
    End With
End Sub

'Writes the room resource columns in the .mps file

Sub RoomColumnEntry(variable)
    roomgrp = Right(variable, 1)
    scenario = IsolateScenario(variable)
    scencol = ScenarioCol(scenario)

    'Gets the days involved in the current scenario
```

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```
      i = 1
      scendays = Sheets("Scenario Confl").Cells(2, scencol)

      'Determines what hour/day slots the scenario will use

      Do While i <= Len(scendays)
         d = EachDay(scendays, i)
         If d = "M" Then dayindex = 1
         If d = "T" Then dayindex = 10
         If d = "W" Then dayindex = 18
         If d = "R" Then dayindex = 26
         If d = "F" Then dayindex = 34

         hour1 = Sheets("Scenario Confl").Cells(3, scencol)
         hour2 = Sheets("Scenario Confl").Cells(4, scencol)
         hour3 = Sheets("Scenario Confl").Cells(5, scencol)

         'Gives time slot index, from 1 to 45 corresponding to
         'whole hours from M at 0800 (Index 1) to F 1600 (Index 45)

         timeslot1 = LTrim(Str((dayindex + (hour1 - 8))))
         If Len(timeslot1) = 1 Then timeslot1 = "0" + timeslot1

         RoomCon1 = "r" + timeslot1 + roomgrp
         Print #9, "     " & variable & "     " & RoomCon1 & "    1.0"

         If hour2 <> "0" Then
            timeslot2 = LTrim(Str((dayindex + (hour2 - 8))))
            If Len(timeslot2) = 1 Then timeslot2 = "0" + timeslot2
            RoomCon2 = "r" + timeslot2 + roomgrp
            Print #9, "     " & variable & "     " & RoomCon2 & "    1.0"
         End If

         If hour3 <> "0" Then
            timeslot3 = LTrim(Str((dayindex + (hour3 - 8))))
            If Len(timeslot3) = 1 Then timeslot3 = "0" + timeslot3
            RoomCon3 = "r" + timeslot3 + roomgrp
            Print #9, "     " & variable & "     " & RoomCon3 & "    1.0"
         End If
         i = i + 1
      Loop
End Sub

'Writes the COLUMNS portion of the .mps File

Sub WriteColumns()

   Print #9, "COLUMNS"

   'Tells solver, all the variable will be integer

   Print #9, "    MARK000    'MARKER'    'INTORG'"

   'Counter for number of variables
   i = 1
```

```vba
   Do While i <= numvbls
      variable = Sheets("Vbl Def").Cells(i, 6).Value
      If variable = "" Then
         i = i + 1
      Else
         impact = Sheets("Vbl Def").Cells(i, 7).Value

         Call InitialColumnEntry(variable, impact)

         Call DeconColumnEntry(variable)

         Call RoomColumnEntry(variable)

         i = i + 1

      End If
   Loop

   'Writes the neurtal variables

   j = 1
   Do While j <= numvbls
      If Sheets("Vbl Def").Cells(j, 6).Value <> "" Then
         variable = Sheets("Vbl Def").Cells(j, 6).Value
         Print #9, "    " & Left(variable, 4) & "000n" & "    " & "a" & Left(variable, 4) & "ij" & "
1.0"
         j = j + 18
      End If
   Loop

   Print #9, "    MARK001   'MARKER'   'INTEND'"

End Sub

'Determines the number of rooms in the room group "grp"

Function GetRoomcap(grp)
   If grp = 1 Then GetRoomcap = 2
   If grp = 2 Then GetRoomcap = 4
   If grp = 3 Then GetRoomcap = 4
   If grp = 4 Then GetRoomcap = 2
   If grp = 5 Then GetRoomcap = 3
   If grp = 6 Then GetRoomcap = 3
   If grp = 7 Then GetRoomcap = 1
   If grp = 8 Then GetRoomcap = 1
   If grp = 9 Then GetRoomcap = 1
End Function

'Writes the RHS portion of the .mps file

Sub WriteRHS()

   Worksheets("Vbl Def").Select
   With ActiveSheet
      Print #9, "RHS"
```

```
      'Writes the single assignments rhs
      i = 1
      Do Until i > numvbls
        If Cells(i, 6).Value = "" Then
          i = i + 18
        Else
          Print #9, "    rhs    " & "a" & Left(Cells(i, 6), 4) & "ij" & "    1.0"
          i = i + 18
        End If
      Loop

      'Writes the deconfliction rhs
      j = 1
      Do Until j > numvbls
        If Cells(j, 6).Value = "" Then
          j = j + 3
        Else
          Print #9, "    rhs    " & "d" & Left(Cells(j, 6), 7) & "i" & "    100.0"
          j = j + 3
        End If
      Loop

      'Writes the room resourse rhs, 45 time slots per week &
      '9 different room groups
      k = 1
      Do Until k > 45
        l = 1
        Do Until l > 9
          If Len(LTrim(Str(k))) = 1 Then
            timeslot = "0" & LTrim(Str(k))
          Else
            timeslot = LTrim(Str(k))
          End If
          roomcap = GetRoomcap(l)
          Print #9, "    rhs    " & "r" & timeslot & l & "     " & roomcap
          l = l + 1
        Loop
        k = k + 1
      Loop

    End With

End Sub

'Closes the output file mpsfile

Sub CloseOutFile()
    Print #9, "ENDATA"
    Close #9
End Sub

Public Sub WriteMps()
    Call GetConstants
    Call OpenOutFile
    Call WriteRows
    Call WriteColumns
```

```
    Call WriteRHS
    Call CloseOutFile
End Sub
'Variables used by two or more subroutines in this module

Dim maxstudents As Integer
Dim numcours As Integer

'This subroutine combines the course name and number and section

Sub CombineDeptNumber()
    i = 1
    Worksheets("Ed Plans").Select
    With ActiveSheet
        Do While Cells(i, 2).Value <> ""
            Cells(i, 8).Value = Cells(i, 2).Value & " " & Cells(i, 3).Value & Cells(i, 4).Value
            i = i + 1
        Loop
    End With
End Sub

'This subroutine develops the course deconfliction matrix rows

Sub DevelopCourseConflicts()
    i = 1
    r = 1
    maxstudents = 0
    Set clearRange = Worksheets("Course SSNs").Range("A1:IV3000")
    clearRange.Clear
    Worksheets("Ed Plans").Select
    With ActiveSheet
        Do While Cells(i, 8).Value <> ""
            course = Cells(i, 8).Value
            j = 0
            m = i
            Do While Cells(m, 8).Value = course
                j = j + 1
                m = m + 1
            Loop
            If j > maxstudents Then maxstudents = j
            Worksheets("Course SSNs").Cells(r, 1).Value = Cells(i, 8).Value
            Worksheets("Course SSNs").Cells(r, 2).Value = Cells(i, 1).Value
            l = i
            k = 3
            Do While l < i + j
                Worksheets("Course SSNs").Cells(r, k).Value = Cells(l, 5).Value
                l = l + 1
                k = k + 1
            Loop
            i = i + j
            r = r + 1
        Loop
    End With
End Sub
```

'This subroutine formats the matrix area

```
Sub InsertRows()
   endrange = maxstudents + 2
   Worksheets("Course SSNs").Select
   With ActiveSheet
      Set xRange = Range(Cells(1, endrange), Cells(endrange, endrange))
      xRange.Select
      Selection.EntireRow.Insert
   End With
End Sub
```

'This subroutine lists the columns portion of the matrix

```
Sub Transpose()
   endrange = maxstudents + 2
   Worksheets("Course SSNs").Select
   With ActiveSheet
      blanks = 0
      i = 1
      Do Until Cells(i, 1) <> ""
         blanks = blanks + 1
         i = i + 1
      Loop
      Do Until Cells(i, 1) = ""
         courses = courses + 1
         i = i + 1
      Loop
      numcours = courses
      Set zRange = Range(Cells(blanks + 1, 1), Cells(blanks + courses, endrange))
      zRange.copy
      Cells(1, (endrange + 2)).Select
      Selection.PasteSpecial Paste:=xlAll, Operation:=xlNone, SkipBlanks:=False _
      , Transpose:=True
   End With
End Sub
```

'This subroutine fills in the course deconfliction matrix

```
Sub WriteMatrix()
   i = maxstudents + 3
   Worksheets("Course SSNs").Select
   With ActiveSheet
      Do Until Cells(i, 1) = ""
         j = 3
         Do Until Cells(i, j) = ""
            k = maxstudents + 4
            Do Until Cells(1, k).Value = ""
               l = 3
               Do While l <= maxstudents + 2
                  If Cells(i, j).Value = Cells(l, k).Value Then
                     Cells(i, k) = 1
                  End If
                  l = l + 1
               Loop
               k = k + 1
            Loop
```

```
            j = j + 1
        Loop
        i = i + 1
    Loop
  End With
End Sub


'This subroutine writes the confliction lists for each course

Sub WriteCourConflicts()
   maxstudents = 36
   numcours = 83
   Worksheets("Course SSNs").Select
   With ActiveSheet
     k = 0
     Set courseIDRange = Range(Cells(2, (maxstudents + 4)), Cells(2, 247))
     courseIDRange.copy
     Worksheets("Course Confl").Select
     With ActiveSheet
       Cells(1, 1).Select
       ActiveSheet.Paste
     End With
     Worksheets("Course SSNs").Select
     Set matrixRange2 = Range(Cells(maxstudents + 3, maxstudents + 4), Cells(maxstudents +
numcours + 3, maxstudents + numcours + 4))
     matrixRange2.Select
     For Each C In matrixRange2
       If C.Value = 1 Then
         i = C.row
         j = C.column
         If Cells(i, 2) <> Cells(2, j) Then
           listColumn = j - (maxstudents + 3)
           Worksheets("Course Confl").Select
           With ActiveSheet
             Range(Cells(3, listColumn), Cells(103, listColumn)).copy
             Cells(4, listColumn).Select
             ActiveSheet.Paste
           End With
           Worksheets("Course   Confl").Cells(3,   listColumn).Value   =   Worksheets("Course
SSNs").Cells(i, 2).Value
           Worksheets("Course SSNs").Select
          End If
        End If
        Next C
   End With
End Sub

'This subroutine calls the other subroutines in this model to develop
'the course deconfliction matrix and lists

Public Sub EdPalns()
   MsgBox Now()
   Call CombineDeptNumber
   Call DevelopCourseConflicts
   Call InsertRows
   Call Transpose
```

```
    Call WriteMatrix
    Call WriteCourConflicts
    MsgBox Now()
End Sub
```

# Appendix D

# Osl Output For "Equal Weighting" Scheduling Variation

Run # 1 -  Scheduling Variation with Departments Weighted
Equally

```
 EKK0008I Description of Problem SchedMps
 EKK0016I          Matrix has 953 rows, 1398 columns and
13830 entries
 EKK0009I Problem Status
 EKK0001I Iteration  Number:       49775; Objective  Value:
84590.00--Optimal
1EKK0011I                          Columns       Section
Page 9
 EKK0063I            ..Name.. Stat  ......Activity......
 EKK0064I       1 x1011905  BS           1.00000000
 EKK0064I      23 x1022012  BS           1.00000000
 EKK0064I      38 x1032031  FX           1.00000000
 EKK0064I      55 x1041902  BS           1.00000000
 EKK0064I      73 x1052175  FX           1.00000000
 EKK0064I      94 x1061343  FX           1.00000000
 EKK0064I     109 x1070549  BS           1.00000000
 EKK0064I     115 x1081995  BS           1.00000000
 EKK0064I     133 x1091762  BS           1.00000000
 EKK0064I     152 x1100609  BS           1.00000000
 EKK0064I     157 x1111273  BS           1.00000000
 EKK0064I     176 x1120569  BS           1.00000000
 EKK0064I     184 x2010902  FX           1.00000000
 EKK0064I     202 x2021204  BS           1.00000000
 EKK0064I     220 x2031242  FX           1.00000000
 EKK0064I     235 x2042456  BS           1.00000000
 EKK0064I     253 x2050913  FX           1.00000000
 EKK0064I     280 x2061223  BS           1.00000000
 EKK0064I     299 x2070924  FX           1.00000000
 EKK0064I     316 x2081223  FX           1.00000000
 EKK0064I     348 x2101243  FX           1.00000000
 EKK0064I     379 x2120307  BS           1.00000000
 EKK0064I     384 x2130884  FX           1.00000000
```

```
EKK0064I        414    x2140314    BS              1.00000000
EKK0064I        432    x2160756    BS              1.00000000
EKK0064I        449    x2170892    FX              1.00000000
EKK0064I        465    x2182066    BS              1.00000000
EKK0064I        475    x2191993    BS              1.00000000
EKK0064I        492    x2202044    BS              1.00000000
EKK0064I        510    x2221213    BS              1.00000000
EKK0064I        534    x2231223    FX              1.00000000
EKK0064I        543    x2241233    BS              1.00000000
EKK0064I        561    x2252456    FX              1.00000000
EKK0064I        567    x2260308    BS              1.00000000
EKK0064I        569    x2270326    BS              1.00000000
EKK0064I        587    x2280893    BS              1.00000000
EKK0064I        606    x2291191    BS              1.00000000
EKK0064I        630    x3012095    FX              1.00000000
EKK0064I        650    x3022045    FX              1.00000000
EKK0064I        669    x3032105    FX              1.00000000
EKK0064I        678    x3042311    BS              1.00000000
EKK0064I        700    x3050522    BS              1.00000000
EKK0064I        711    x3062379    BS              1.00000000
EKK0064I        723    x3071932    FX              1.00000000
EKK0064I        734    x3080267    BS              1.00000000
EKK0064I        739    x3090885    FX              1.00000000
EKK0064I        754    x3100955    BS              1.00000000
EKK0064I        772    x3111992    FX              1.00000000
EKK0064I        796    x3122283    FX              1.00000000
EKK0064I        811    x3132002    FX              1.00000000
EKK0064I        829    x3141322    FX              1.00000000
EKK0064I        847    x3152452    FX              1.00000000
EKK0064I        861    x3161911    FX              1.00000000
EKK0064I        871    x3170017    FX              1.00000000
EKK0064I        885    x4010767    FX              1.00000000
EKK0064I        887    x4020974    FX              1.00000000
EKK0064I        908    x4030884    FX              1.00000000
EKK0064I        926    x4040881    FX              1.00000000
EKK0064I        944    x4050305    FX              1.00000000
EKK0064I        962    x4062275    FX              1.00000000
EKK0064I        977    x4070924    FX              1.00000000
EKK0064I        992    x4080914    FX              1.00000000
EKK0064I       1010    x4090944    FX              1.00000000
EKK0064I       1037    x5010901    FX              1.00000000
EKK0064I       1046    x5020202    FX              1.00000000
EKK0064I       1070    x5030993    FX              1.00000000
EKK0064I       1085    x5040963    FX              1.00000000
EKK0064I       1103    x5051263    FX              1.00000000
EKK0064I       1121    x6011323    FX              1.00000000
EKK0064I       1145    x6020975    FX              1.00000000
```

```
EKK0064I      1154   x6030865   FX            1.00000000
EKK0064I      1172   x6040945   FX            1.00000000
EKK0064I      1192   x6050861   FX            1.00000000
EKK0064I      1223   x6060893   FX            1.00000000
EKK0064I      1235   x6072013   FX            1.00000000
EKK0064I      1247   x6082003   FX            1.00000000
EKK0064I      1265   x6091003   FX            1.00000000
EKK0064I      1287   x6102417   FX            1.00000000
EKK0064I      1301   x6111913   FX            1.00000000
EKK0064I      1336   x209000n   FX            1.00000000
EKK0064I      1338   x211000n   FX            1.00000000
EKK0064I      1342   x215000n   FX            1.00000000
EKK0064I      1348   x221000n   FX            1.00000000
```

*** An optimal integer solution has been found ***


*** Application terminated ***

# Appendix E

# Osl Output For "Number Of Courses Weighting" Scheduling Variation


```
 Run # 2 - Scheduling Variation where Department Weights
based upon Number of Courses
       being taught.


 EKK0008I Description of Problem SchedMps
 EKK0016I          Matrix has 953 rows, 1398 columns and
13830 entries
 EKK0009I Problem Status
 EKK0006I  Optimization  Subroutine  Library  Version  1.3
(76162)        Page 62
 EKK0001I  Iteration  Number:        65817;  Objective  Value:
83163.00--Optimal
 EKK0011I                             Columns        Section
Page 63
 EKK0063I              ..Name.. Stat  ......Activity......
 EKK0064I        2  x1011902   BS           1.00000000
 EKK0064I       22  x1022015   BS           1.00000000
 EKK0064I       38  x1032031   FX           1.00000000
 EKK0064I       55  x1041902   FX           1.00000000
 EKK0064I       73  x1052175   FX           1.00000000
 EKK0064I       92  x1061331   BS           1.00000000
 EKK0064I      109  x1070549   BS           1.00000000
 EKK0064I      115  x1081995   FX           1.00000000
 EKK0064I      133  x1091762   BS           1.00000000
 EKK0064I      152  x1100609   FX           1.00000000
 EKK0064I      157  x1111273   FX           1.00000000
 EKK0064I      176  x1120569   BS           1.00000000
 EKK0064I      184  x2010902   FX           1.00000000
 EKK0064I      202  x2021204   BS           1.00000000
 EKK0064I      220  x2031242   BS           1.00000000
 EKK0064I      235  x2042456   BS           1.00000000
 EKK0064I      256  x2050923   FX           1.00000000
 EKK0064I      280  x2061223   FX           1.00000000
 EKK0064I      299  x2070924   BS           1.00000000
```

```
EKK0064I        316   x2081223   FX                     1.00000000
EKK0064I        347   x2101241   BS                     1.00000000
EKK0064I        379   x2120307   BS                     1.00000000
EKK0064I        384   x2130884   BS                     1.00000000
EKK0064I        416   x2140318   FX                     1.00000000
EKK0064I        417   x2150873   FX                     1.00000000
EKK0064I        432   x2160756   BS                     1.00000000
EKK0064I        448   x2170893   BS                     1.00000000
EKK0064I        465   x2182066   FX                     1.00000000
EKK0064I        474   x2191995   FX                     1.00000000
EKK0064I        492   x2202044   BS                     1.00000000
EKK0064I        510   x2221213   BS                     1.00000000
EKK0064I        534   x2231223   FX                     1.00000000
EKK0064I        543   x2241233   FX                     1.00000000
EKK0064I        561   x2252456   BS                     1.00000000
EKK0064I        567   x2260308   BS                     1.00000000
EKK0064I        569   x2270326   FX                     1.00000000
EKK0064I        587   x2280893   FX                     1.00000000
EKK0064I        605   x2291195   FX                     1.00000000
EKK0064I        629   x3012091   BS                     1.00000000
EKK0064I        650   x3022045   FX                     1.00000000
EKK0064I        668   x3032101   FX                     1.00000000
EKK0064I        677   x3042315   BS                     1.00000000
EKK0064I        696   x3050511   FX                     1.00000000
EKK0064I        711   x3062379   BS                     1.00000000
EKK0064I        723   x3071932   FX                     1.00000000
EKK0064I        732   x3080277   BS                     1.00000000
EKK0064I        739   x3090885   BS                     1.00000000
EKK0064I        754   x3100955   BS                     1.00000000
EKK0064I        772   x3111992   FX                     1.00000000
EKK0064I        796   x3122283   FX                     1.00000000
EKK0064I        813   x3132004   FX                     1.00000000
EKK0064I        829   x3141322   FX                     1.00000000
EKK0064I        847   x3152452   FX                     1.00000000
EKK0064I        859   x3161912   BS                     1.00000000
EKK0064I        881   x3170067   BS                     1.00000000
EKK0064I        883   x4010757   BS                     1.00000000
EKK0064I        887   x4020974   BS                     1.00000000
EKK0064I        908   x4030884   BS                     1.00000000
EKK0064I        926   x4040881   BS                     1.00000000
EKK0064I        941   x4050295   FX                     1.00000000
EKK0064I        962   x4062275   FX                     1.00000000
EKK0064I        977   x4070924   FX                     1.00000000
EKK0064I        995   x4080924   FX                     1.00000000
EKK0064I       1010   x4090944   FX                     1.00000000
EKK0064I       1039   x5010905   FX                     1.00000000
EKK0064I       1046   x5020202   FX                     1.00000000
```

```
EKK0064I        1073  x5031003    FX                1.00000000
EKK0064I        1082  x5040953    FX                1.00000000
EKK0064I        1103  x5051263    FX                1.00000000
EKK0064I        1121  x6011323    FX                1.00000000
EKK0064I        1142  x6020965    FX                1.00000000
EKK0064I        1154  x6030865    FX                1.00000000
EKK0064I        1172  x6040945    FX                1.00000000
EKK0064I        1190  x6050865    FX                1.00000000
EKK0064I        1217  x6060883    FX                1.00000000
EKK0064I        1236  x6072012    FX                1.00000000
EKK0064I        1250  x6082033    FX                1.00000000
EKK0064I        1265  x6091003    FX                1.00000000
EKK0064I        1307  x6111933    FX                1.00000000
EKK0064I        1336  x209000n    FX                1.00000000
EKK0064I        1338  x211000n    FX                1.00000000
EKK0064I        1348  x221000n    FX                1.00000000
EKK0064I        1397  x610000n    FX                1.00000000
```

*** An optimal integer solution has been found ***


*** Application terminated ***

# Appendix F

# Osl Output For "Number Of Students Weighting" Scheduling Variation

```
 Run # 4 - Department Weights based upon number of Students
being taught
 EKK0008I Description of Problem SchedMps
 EKK0016I            Matrix has 953 rows, 1398 columns and
13830 entries
 EKK0009I Problem Status
 EKK3000W  Iteration  Number:       37223;  Objective  Value:
84868.00--Infeasible
 EKK0003I  The  sum  of  the  primal  infeasibilities  is
4.337215D-07, and the number of primal infeasibilities is 1
 1EKK0011I                            Columns        Section
Page 11
 EKK0063I              ..Name.. Stat  ......Activity......
 EKK0064I         1  x1011905  BS            1.00000000
 EKK0064I        22  x1022015  FX            1.00000000
 EKK0064I        40  x1032042  FX            1.00000000
 EKK0064I        67  x1041892  BS            1.00000000
 EKK0064I        74  x1052172  FX            1.00000000
 EKK0064I        94  x1061343  BS            1.00000000
 EKK0064I       110  x1070629  FX            1.00000000
 EKK0064I       115  x1081995  FX            1.00000000
 EKK0064I       133  x1091762  BS            1.00000000
 EKK0064I       152  x1100609  FX            1.00000000
 EKK0064I       157  x1111273  FX            1.00000000
 EKK0064I       176  x1120569  BS            1.00000000
 EKK0064I       184  x2010902  FX            1.00000000
 EKK0064I       202  x2021204  FX            1.00000000
 EKK0064I       220  x2031242  BS            1.00000000
 EKK0064I       235  x2042456  BS            1.00000000
 EKK0064I       256  x2050923  BS            1.00000000
 EKK0064I       280  x2061223  FX            1.00000000
 EKK0064I       298  x2070923  FX            1.00000000
 EKK0064I       316  x2081223  FX            1.00000000
```

```
EKK0064I        325  x2091005  FX              1.00000000
EKK0064I        352  x2100935  FX              1.00000000
EKK0064I        379  x2120307  BS              1.00000000
EKK0064I        384  x2130884  BS              1.00000000
EKK0064I        409  x2140297  FX              1.00000000
EKK0064I        417  x2150873  BS              1.00000000
EKK0064I        432  x2160756  BS              1.00000000
EKK0064I        447  x2170895  BS              1.00000000
EKK0064I        465  x2182066  FX              1.00000000
EKK0064I        475  x2191993  BS              1.00000000
EKK0064I        492  x2202044  FX              1.00000000
EKK0064I        510  x2221213  FX              1.00000000
EKK0064I        534  x2231223  BS              1.00000000
EKK0064I        546  x2241243  BS              1.00000000
EKK0064I        561  x2252456  FX              1.00000000
EKK0064I        567  x2260308  BS              1.00000000
EKK0064I        569  x2270326  BS              1.00000000
EKK0064I        590  x2280903  BS              1.00000000
EKK0064I        605  x2291195  BS              1.00000000
EKK0064I        632  x3012101  BS              1.00000000
EKK0064I        650  x3022045  FX              1.00000000
EKK0064I        666  x3032095  BS              1.00000000
EKK0064I        677  x3042315  BS              1.00000000
EKK0064I        698  x3050523  FX              1.00000000
EKK0064I        710  x3062369  BS              1.00000000
EKK0064I        723  x3071932  FX              1.00000000
EKK0064I        734  x3080267  FX              1.00000000
EKK0064I        739  x3090885  BS              1.00000000
EKK0064I        754  x3100955  FX              1.00000000
EKK0064I        772  x3111992  BS              1.00000000
EKK0064I        796  x3122283  FX              1.00000000
EKK0064I        822  x3132034  FX              1.00000000
EKK0064I        829  x3141322  FX              1.00000000
1EKK0011I                                Columns        Section
 Page 12
 EKK0063I              ..Name..  Stat  ......Activity......
 EKK0064I        847  x3152452  FX              1.00000000
 EKK0064I        861  x3161911  FX              1.00000000
 EKK0064I        882  x3170068  FX              1.00000000
 EKK0064I        883  x4010757  FX              1.00000000
 EKK0064I        887  x4020974  FX              1.00000000
 EKK0064I        908  x4030884  FX              1.00000000
 EKK0064I        926  x4040881  FX              1.00000000
 EKK0064I        944  x4050305  FX              1.00000000
 EKK0064I        962  x4062275  FX              1.00000000
 EKK0064I        977  x4070924  FX              1.00000000
 EKK0064I        995  x4080924  FX              1.00000000
```

```
EKK0064I      1010  x4090944   FX                1.00000000
EKK0064I      1038  x5010902   FX                1.00000000
EKK0064I      1046  x5020202   FX                1.00000000
EKK0064I      1073  x5031003   FX                1.00000000
EKK0064I      1082  x5040953   FX                1.00000000
EKK0064I      1103  x5051263   FX                1.00000000
EKK0064I      1121  x6011323   FX                1.00000000
EKK0064I      1142  x6020965   FX                0.99999993
EKK0064I      1143  x6020964   FX      0.655040660602D-07
EKK0064I      1154  x6030865   FX                1.00000000
EKK0064I      1172  x6040945   FX                1.00000000
EKK0064I      1191  x6050863   FX                1.00000000
EKK0064I      1217  x6060883   FX                1.00000000
EKK0064I      1235  x6072013   FX                1.00000000
EKK0064I      1250  x6082033   FX                1.00000000
EKK0064I      1265  x6091003   FX                1.00000000
EKK0064I      1307  x6111933   FX                1.00000000
EKK0064I      1338  x211000n   FX                1.00000000
EKK0064I      1348  x221000n   FX                1.00000000
EKK0064I      1397  x610000n   FX                1.00000000
```

*** An optimal integer solution has been found ***


*** Application terminated ***

# Appendix G

# Osl Output For "Number Of Course With Lectures Given Weighting" Scheduling Variation

```
 Run # 3 - Department Weights based upon Number of Courses
being taught with each
          department's siminars weighted highly to insure
scheduling at first preference

 EKK0008I Description of Problem SchedMps
 EKK0016I            Matrix has 953 rows, 1398 columns and
13830 entries
 EKK0009I Problem Status
 EKK0001I  Iteration  Number:       39012;  Objective  Value:
155038.0--Optimal
1EKK0011I                             Columns        Section
Page 12
 EKK0063I               ..Name..  Stat  ......Activity......
 EKK0064I           3  x1011903   BS          1.00000000
 EKK0064I          25  x1022055   FX          1.00000000
 EKK0064I          37  x1032032   FX          1.00000000
 EKK0064I          55  x1041902   FX          1.00000000
 EKK0064I          73  x1052175   FX          1.00000000
 EKK0064I          91  x1061333   BS          1.00000000
 EKK0064I         109  x1070549   FX          1.00000000
 EKK0064I         115  x1081995   BS          1.00000000
 EKK0064I         133  x1091762   FX          1.00000000
 EKK0064I         152  x1100609   BS          1.00000000
 EKK0064I         157  x1111273   FX          1.00000000
 EKK0064I         176  x1120569   FX          1.00000000
 EKK0064I         184  x2010902   FX          1.00000000
 EKK0064I         202  x2021204   FX          1.00000000
 EKK0064I         220  x2031242   BS          1.00000000
 EKK0064I         235  x2042456   BS          1.00000000
 EKK0064I         256  x2050923   FX          1.00000000
 EKK0064I         280  x2061223   BS          1.00000000
 EKK0064I         299  x2070924   FX          1.00000000
 EKK0064I         316  x2081223   BS          1.00000000
```

```
EKK0064I      348  x2101243   BS              1.00000000
EKK0064I      379  x2120307   BS              1.00000000
EKK0064I      384  x2130884   BS              1.00000000
EKK0064I      415  x2140317   FX              1.00000000
EKK0064I      420  x2150883   FX              1.00000000
EKK0064I      433  x2160766   FX              1.00000000
EKK0064I      451  x2170903   FX              1.00000000
EKK0064I      465  x2182066   FX              1.00000000
EKK0064I      474  x2191995   FX              1.00000000
EKK0064I      492  x2202044   FX              1.00000000
EKK0064I      510  x2221213   BS              1.00000000
EKK0064I      534  x2231223   FX              1.00000000
EKK0064I      546  x2241243   BS              1.00000000
EKK0064I      561  x2252456   BS              1.00000000
EKK0064I      567  x2260308   BS              1.00000000
EKK0064I      569  x2270326   BS              1.00000000
EKK0064I      590  x2280903   BS              1.00000000
EKK0064I      605  x2291195   FX              1.00000000
EKK0064I      629  x3012091   FX              1.00000000
EKK0064I      650  x3022045   FX              1.00000000
EKK0064I      668  x3032101   FX              1.00000000
EKK0064I      678  x3042311   FX              1.00000000
EKK0064I      695  x3050513   BS              1.00000000
EKK0064I      711  x3062379   FX              1.00000000
EKK0064I      723  x3071932   BS              1.00000000
EKK0064I      732  x3080277   FX              1.00000000
EKK0064I      739  x3090885   BS              1.00000000
EKK0064I      754  x3100955   FX              1.00000000
EKK0064I      772  x3111992   BS              1.00000000
EKK0064I      796  x3122283   FX              1.00000000
EKK0064I      812  x3132003   FX              1.00000000
EKK0064I      829  x3141322   FX              1.00000000
EKK0064I      847  x3152452   FX              1.00000000
1EKK0011I                                Columns        Section
 Page 13
 EKK0063I                  ..Name.. Stat  ......Activity......
 EKK0064I      861  x3161911   FX              1.00000000
 EKK0064I      881  x3170067   FX              1.00000000
 EKK0064I      883  x4010757   FX              1.00000000
 EKK0064I      887  x4020974   FX              1.00000000
 EKK0064I      908  x4030884   FX              1.00000000
 EKK0064I      926  x4040881   FX              1.00000000
 EKK0064I      941  x4050295   FX              1.00000000
 EKK0064I      962  x4062275   FX              1.00000000
 EKK0064I      977  x4070924   FX              1.00000000
 EKK0064I      992  x4080914   FX              1.00000000
 EKK0064I     1010  x4090944   FX              1.00000000
```

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```
EKK0064I       1037   x5010901   FX             1.00000000
EKK0064I       1046   x5020202   FX             1.00000000
EKK0064I       1073   x5031003   FX             1.00000000
EKK0064I       1082   x5040953   FX             1.00000000
EKK0064I       1103   x5051263   FX             1.00000000
EKK0064I       1124   x6011273   FX             1.00000000
EKK0064I       1145   x6020975   FX             1.00000000
EKK0064I       1154   x6030865   FX             1.00000000
EKK0064I       1174   x6040942   FX             1.00000000
EKK0064I       1199   x6050895   FX             1.00000000
EKK0064I       1211   x6062003   FX             1.00000000
EKK0064I       1232   x6072003   FX             1.00000000
EKK0064I       1262   x6090993   FX             1.00000000
EKK0064I       1283   x6102396   FX             1.00000000
EKK0064I       1310   x6111943   FX             1.00000000
EKK0064I       1336   x209000n   FX             1.00000000
EKK0064I       1338   x211000n   FX             1.00000000
EKK0064I       1348   x221000n   FX             1.00000000
EKK0064I       1395   x608000n   FX             1.00000000
```

*** An optimal integer solution has been found ***


*** Application terminated ***

<div align="center">

**Appendix H**

**EDSSS User Manual**

</div>

## Preface

This user manual is written in support of the Educational Decision Support and Scheduling System (EDSSS), developed 1Lt Shane Knighton, as part of the thesis research entitled "A Value Focused Approach to Academic Course Scheduling." This manual assumes the user has a working knowledge of MicroSoft Excel 97 and DOS. The programs use code written in Visual Basic within MS Excel. The user operating EDSSS is assumed to be the academic course scheduler and is herein referred to as the scheduler. Notes and Cautions are provided in *italics* throughout the manual. A Note is used to provide the user with information that will help EDSSS run smoothly, a Caution provides information that may cause the program to execute incorrectly.

## Introduction

The Educational Decision Support and Scheduling System (EDSSS) assigns academic courses for the School of Engineering (EN) of AFIT to days, times, and rooms. The system will not allow student or instructor conflicts and will not utilize more rooms than are available within the EN building. If more in-depth information is required about the methodology used by EDSSS, the user is referred to the thesis by 1Lt Shane Knighton entitled "A Value Focused Thinking Approach to Academic Course Scheduling."

<div align="center">73</div>

EDSSS is comprised of three different programs:

1) Electronic Questionnaire

2) Mixed Integer Program Problem Generator

3) Optimization Subroutine Library

The flowchart on the following page gives the user an overview of how each of these programs interact. A more detailed description of each program is provided.

Prior to using EDSSS to produce an academic schedule, a finalized course listing from each department is required. The course listing must contain the name of the instructor for each course listed. The scheduler must then assign a three-digit course ID number to each of the courses.

*NOTE: It is suggested that the ID numbers be assigned in the following manner. The first digit of a course offered by ENC is 1; the final two digits are assigned as the order listed on the proposed course listing. In a similar fashion, the first digit of courses offered by ENG, ENP, ENS, ENV, and ENY will be 2, 3, 4, 5, and 6 respectively.*

Additionally, a query from the Education Plans database is needed prior to scheduling. The query must list the department, course number, section/lab number, and the SSN of all students enrolled in that course. The course ID number is added to the first column of the list. The ID number must be repeated for every SSN in the same course. The query must be in the form shown by Figure 1 of this manual.

Electronic Questionnaire

Preferences Entry

| 213 | 0.9 | 0.1 | 087 | 088 | 091 | 092 | 089 | 090 | 4 | 3 | 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|

Preference Table

Non - Preferences

Set of Neutral Variables, Fill out preference table (**entries in bold**)

Value Hierarchy Weights

### Variable List

| 101 | 190 | 1 | 5 | 0.333 | x1011905 | 1388 |
|---|---|---|---|---|---|---|
|  |  | 1 | 2 | 0.333 | x1011902 | 1388 |
|  |  | 1 | 3 | 0.333 | x1011903 | 1388 |
|  | 191 | 1 | 5 | 0.333 | x1011915 | 1388 |
|  |  | 1 | 2 | 0.333 | x1011912 | 1388 |
|  |  | 1 | 3 | 0.333 | x1011913 | 1388 |
|  | 095 | 0.833 | 5 | 0.333 | x1010955 | 1156 |
|  |  | 0.833 | 2 | 0.333 | x1010952 | 1156 |
|  |  | 0.833 | 3 | 0.333 | x1010953 | 1156 |
|  | 096 | 0.833 | 5 | 0.333 | x1010965 | 1156 |
|  |  | 0.833 | 2 | 0.333 | x1010962 | 1156 |
|  |  | 0.833 | 3 | 0.333 | x1010963 | 1156 |
|  | 119 | 0.667 | 5 | 0.333 | x1011195 | 926 |
|  |  | 0.667 | 2 | 0.333 | x1011192 | 926 |
|  |  | 0.667 | 3 | 0.333 | x1011193 | 926 |
|  | 120 | 0.667 | 5 | 0.333 | x1011205 | 926 |
|  |  | 0.667 | 2 | 0.333 | x1011202 | 926 |
|  |  | 0.667 | 3 | 0.333 | x1011203 | 694 |
| 102 | 198 | 0.333 | 5 | 0.333 | x1021985 | 462 |
|  |  | 0.333 | 2 | 0.333 | x1021982 | 462 |
|  |  | 0.333 | 1 | 0.333 | x1021981 | 462 |
|  | 201 | 0.333 | 5 | 0.333 | x1022015 | 462 |
|  |  | 0.333 | 2 | 0.333 | x1022012 | 462 |
|  |  | 0.333 | 1 | 0.333 | x1022011 | 462 |
|  | 205 | 0.333 | 5 | 0.333 | x1022055 | 462 |
|  |  | 0.333 | 2 | 0.333 | x1022052 | 462 |
|  |  | 0.333 | 1 | 0.333 | x1022051 | 462 |
|  | 206 | 0.333 | 5 | 0.333 | x1022065 | 462 |
|  |  | 0.333 | 2 | 0.333 | x1022062 | 462 |
|  |  | 0.333 | 1 | 0.333 | x1022061 | 462 |
|  | 223 | 0.333 | 5 | 0.333 | x1022235 | 462 |
|  |  | 0.333 | 2 | 0.333 | x1022232 | 462 |
|  |  | 0.333 | 1 | 0.333 | x1022231 | 462 |
|  | 224 | 0.333 | 5 | 0.333 | x1022245 | 462 |
|  |  | 0.333 | 2 | 0.333 | x1022242 | 462 |
|  |  | 0.333 | 1 | 0.333 | x1022241 | 462 |
| 103 | 203 | 1 | 2 | 1 | x1032032 | 1388 |
|  |  | 1 | 1 | 0.333 | x1032031 | 1388 |
|  |  | 1 | 3 | 0.333 | x1032033 | 1388 |
|  | 204 | 1 | 2 | 1 | x1032042 | 1388 |
|  |  | 1 | 1 | 0.333 | x1032041 | 1388 |
|  |  | 1 | 3 | 0.333 | x1032043 | 1388 |
|  | 205 | 0.833 | 2 | 1 | x1032052 | 1156 |
|  |  | 0.833 | 1 | 0.333 | x1032051 | 1156 |
|  |  | 0.833 | 3 | 0.333 | x1032053 | 1156 |
|  | 206 | 0.833 | 2 | 1 | x1032062 | 1156 |
|  |  | 0.833 | 1 | 0.333 | x1032061 | 1156 |
|  |  | 0.833 | 3 | 0.333 | x1032063 | 1156 |
|  | 201 | 0.333 | 2 | 1 | x1032012 | 462 |
|  |  | 0.333 | 1 | 0.333 | x1032011 | 462 |
|  |  | 0.333 | 3 | 0.333 | x1032013 | 462 |
|  | 202 | 0.333 | 2 | 1 | x1032022 | 462 |
|  |  | 0.333 | 1 | 0.333 | x1032021 | 462 |
|  |  | 0.333 | 3 | 0.333 | x1032023 | 462 |

### Ed Plans List by SSN

| 101 | MATH | 508 | 01 | 002-78-1969 |
|---|---|---|---|---|
| 101 | MATH | 508 | 01 | 061-58-6522 |
| 101 | MATH | 508 | 01 | 116-56-4832 |
| 101 | MATH | 508 | 01 | 226-27-8496 |
| 101 | MATH | 508 | 01 | 408-55-1091 |
| 101 | MATH | 508 | 01 | 417-19-0228 |
| 101 | MATH | 508 | 01 | 445-68-9745 |
| 101 | MATH | 508 | 01 | 526-13-8757 |
| 101 | MATH | 508 | 01 | 546-45-5750 |
| 102 | MATH | 521 | 01 | 077-68-9156 |
| 102 | MATH | 521 | 01 | 152-76-8630 |
| 102 | MATH | 521 | 01 | 278-88-7980 |
| 102 | MATH | 521 | 01 | 550-29-9749 |
| 102 | MATH | 521 | 01 | 558-43-9859 |
| 102 | MATH | 521 | 01 | 567-75-3710 |
| 103 | MATH | 633 | 01 | 000-000-001 |
| 104 | MATH | 674 | 01 | 261-73-9432 |
| 104 | MATH | 674 | 01 | 312-94-1786 |
| 104 | MATH | 674 | 01 | 504-78-8469 |
| 104 | MATH | 674 | 01 | 000-00-002 |
| 105 | MATH | 705 | 01 | 000-00-003 |
| 106 | STAT | 528 | 01 | 017-62-8627 |

### Scenario Conflict List

| 005 | 006 | 007 |
|---|---|---|
| 220 | 239 | 239 |
| 211 | 235 | 235 |
| 202 | 221 | 222 |
| 193 | 212 | 213 |
| 166 | 203 | 204 |
| 157 | 194 | 195 |
| 148 | 167 | 168 |
| 139 | 158 | 159 |
| 130 | 149 | 150 |
| 114 | 140 | 141 |
| 113 | 131 | 132 |
| 106 | 115 | 116 |
| 105 | 114 | 115 |
| 090 | 107 | 108 |
| 089 | 106 | 107 |
| 050 | 091 | 092 |
| 049 | 090 | 091 |
| 005 | 051 | 052 |
|  | 050 | 051 |
|  | 006 | 007 |

### Course Conflict Matrix

### Course Conflict List

| 109 | 110 | 111 |
|---|---|---|
| 603 | 603 | 409 |
| 409 | 409 | 408 |
| 407 | 407 | 407 |
| 406 | 406 | 404 |
| 403 | 403 | 403 |
| 402 | 402 | 401 |
| 401 | 401 | 211 |
| 110 | 109 | 112 |

Schedule

OSL Mixed Integer Solver

Mixed Integer Program in MPS format

*Caution: The list must be sorted by ID number. All identical ID numbers must be grouped together in the list. The program assumes that if a new ID number is encountered, all SSN for the previous ID number have been counted.*

*Caution: The Ed Plan List must contain information for every course given an ID. If the list is not complete, the scheduler must include the missing courses in the list prior to scheduling. The scheduler must enter the missing courses in the same format as the rest of the list, however no SSN should be given.*

| 101 | MATH | 508 | 01 | 002-78-1969 |
|-----|------|-----|----|-------------|
| 101 | MATH | 508 | 01 | 061-58-6522 |
| 101 | MATH | 508 | 01 | 116-56-4832 |
| 101 | MATH | 508 | 01 | 226-27-8496 |
| 101 | MATH | 508 | 01 | 408-55-1091 |
| 101 | MATH | 508 | 01 | 417-19-0228 |
| 101 | MATH | 508 | 01 | 445-68-9745 |
| 101 | MATH | 508 | 01 | 526-13-8757 |
| 101 | MATH | 508 | 01 | 546-45-5750 |
| 102 | MATH | 521 | 01 | 077-68-9156 |
| 102 | MATH | 521 | 01 | 152-76-8630 |
| 102 | MATH | 521 | 01 | 278-88-7980 |
| 102 | MATH | 521 | 01 | 550-29-9749 |
| 102 | MATH | 521 | 01 | 558-43-9859 |
| 102 | MATH | 521 | 01 | 567-75-3710 |
| 103 | MATH | 633 | 01 | 000-000-001 |
| 104 | MATH | 674 | 01 | 261-73-9432 |
| 104 | MATH | 674 | 01 | 312-94-1786 |
| 104 | MATH | 674 | 01 | 504-78-8469 |
| 104 | MATH | 674 | 01 | 000-00-002 |
| 105 | MATH | 705 | 01 | 000-00-003 |
| 106 | STAT | 528 | 01 | 017-62-8627 |
| 106 | STAT | 528 | 01 | 023-52-7817 |
| 106 | STAT | 528 | 01 | 263-63-8302 |
| 106 | STAT | 528 | 01 | 399-68-3166 |
| 106 | STAT | 528 | 01 | 414-49-4391 |
| 106 | STAT | 528 | 01 | 459-79-1577 |
| 106 | STAT | 528 | 01 | 460-33-1803 |
| 106 | STAT | 528 | 01 | 480-60-4053 |
| 107 | STAT | 528 | 91 | 017-62-8627 |
| 107 | STAT | 528 | 91 | 023-52-7817 |
| 107 | STAT | 528 | 91 | 263-63-8302 |
| 107 | STAT | 528 | 91 | 399-68-3166 |
| 107 | STAT | 528 | 91 | 414-49-4391 |
| 107 | STAT | 528 | 91 | 459-79-1577 |
| 107 | STAT | 528 | 91 | 460-33-1803 |
| 107 | STAT | 528 | 91 | 480-60-4053 |

**Figure 1: Example of Ed Plan Query**

**Electronic Questionnaire**

The electronic questionnaire is a set of Windows dialogue boxes which run in MS Excel. The purpose of the questionnaire is to capture the day/time preferences, day/time non-preferences, and room preferences of the instructor for each course to be scheduled. This questionnaire can be delivered to each instructor via E-mail or place in a central location accessible to everyone being scheduled.

*Note: Instructors teaching more that one course must fill out a different questionnaire for each course to be scheduled.*

The initial screen offers the user two options. Single clicking on the INSTRUCTIONS option button provides instructions on filling out the questionnaire. Single clicking on the FACULTY PREFERENCES option button displays the following dialogue box.
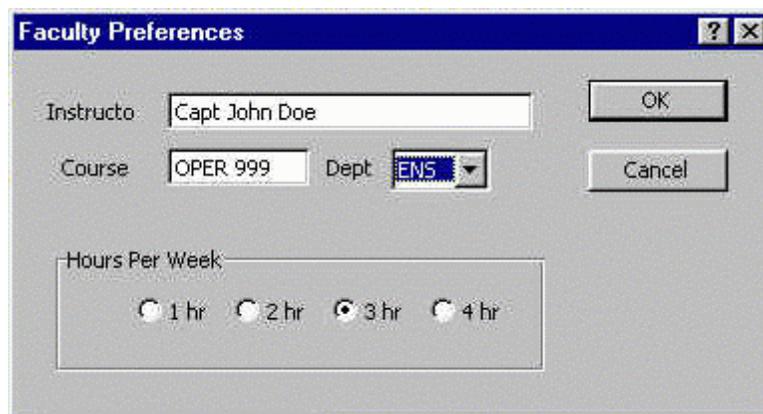


**Figure 2: Faculty Preferences Dialogue Box # 1**

The instructors must fill in their name, course, department, and course ID. The ID number should be assigned to each instructor prior to delivering the questionnaire. Additionally, the instructor must indicate the number of hours their course meets per week.

*Caution: The number of hours the course meets per week must be indicated correctly. The choices for day combinations differ according to the number of hours indicated.*

Once the information has been entered, single click the OK button, this will automatically display the dialogue box containing the available day/time scenarios. The instructor can fill out the preferences and non-preferences by selecting an entry from the appropriate dropdown list. The day/time weight must be placed in the appropriate box and be within the range of 0 to 1. An example of the preferences dialogue box is shown in Figure 3 of this manual.
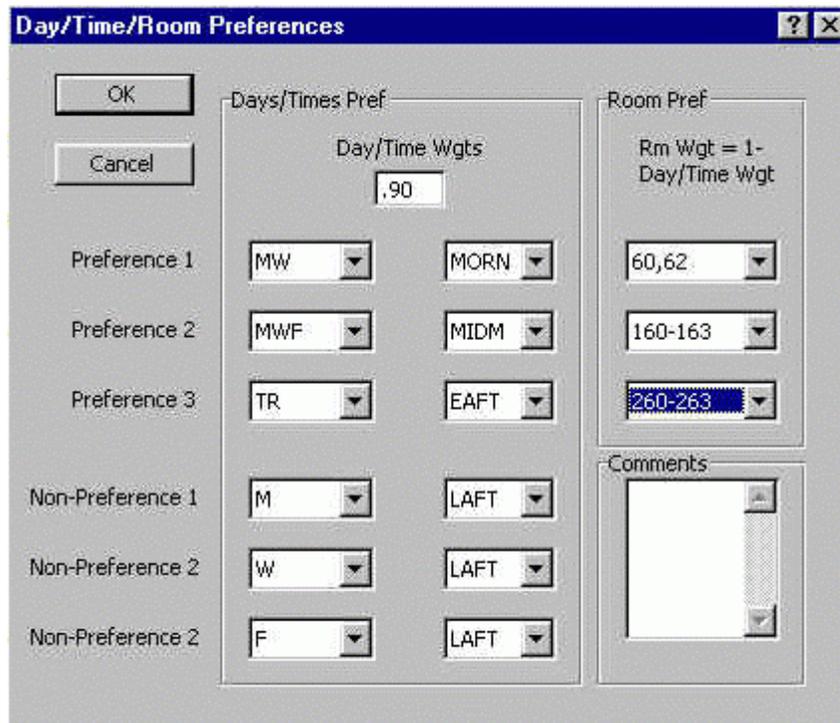
**Figure 3: Faculty Preferences Dialogue Box #2**

*Note: If no day/time weight is indicated the weighting is selected by the scheduler.*

Once the instructor completes the questionnaire, the preferences are put into Range B1:B12 on the PREFERENCES sheet of the electronic questionnaire. This Range is the entry for the course in the Preference Table of the Mixed Integer Problem Generator. The instructor's non-preferences for day/time scenarios are shown in Range E1:E6.

**Mixed Integer Problem Generator**

The Mixed Integer Problem Generator is an MS Excel spreadsheet using a suite of Visual Basic Modules. The purpose of the problem generator is to construct the Mixed Integer Academic Scheduling Problem in Mathematical Programming System (MPS) format. This file is read by OSL, the Mixed Integer Solver. Open the problem generator in MS Excel 97.

The scheduler is required to update four Ranges before running the problem generator. Initially, the scheduler should enter the weights for each department and the courses to be scheduled on the VALUE HIERARCHY sheet.

*Note: The weights for each Department should come from the Dean or his staff, while the weights for each course are given by the respective Department Heads.*

*Caution: An entry in the Value Hierarchy, i.e. course ID and weight, is required for every course in the Preference Table.*

The three remaining Ranges to be updated are located on the CODE DATA sheet. The Ed Plan query, in the format shown by Figure 1 of this manual, should be placed in Range A12:D12. The Preference Table is built by combining the entries from all the instructors' individual preference entries. These entries were obtained via the Electronic Questionnaire, refer to that portion of this manual for further information. The entries are placed on consecutive rows, with the first entry being placed in Range I12:T12.

If the instructor did not completely fill out the questionnaire, the scheduler using neutral preferences can complete the entry. Neutral preferences are defined as the day/time scenarios not given as non-preferences by the instructor via the electronic questionnaire. Neutral preferences for day/time scenarios and room groups must be indicated as such by using **bold font** for the neutral scenario and room group numbers in the preferences entry for that course.

The final range is located in cells, C2:C7. The number of courses to be scheduled is entered into cell C2. Cells C3:C5 are used by the program and should not be changed. The path and filename of the file created that contains the Mixed Integer Program in MPS is entered in Cells C6:C7. Once all of the above tasks have been completed, single clicking the WRITE MPS FILE button on the CODE DATA sheet creates the MPS file named in cell C7. The following figure shows an updated CODE DATA sheet.

| NumCourses | 83 |
|---|---|
| NumScenarios | 245 |
| Decon Penalty | 100 |
| NumVariables | 1494 |
| Path | c:\thesis\Final Model\ |
| Filename | run1.mps |

Educational Decision Support & Scheduling System
AFIT School of Engineering
Developed In Support of Thesis Research Conducted by:     1Lt Shane Knighton /GOR
    Advisors:     LtC Jack Jackson
    Dr Dick Deckro

**Education Plan Query**

| | | | | |
|---|---|---|---|---|
| 101 | MATH | 508 | 01 | 002-78-1969 |
| 101 | MATH | 508 | 01 | 061-58-6522 |
| 101 | MATH | 508 | 01 | 116-56-4832 |
| 101 | MATH | 508 | 01 | 226-27-8496 |
| 101 | MATH | 508 | 01 | 408-55-1091 |
| 101 | MATH | 508 | 01 | 417-19-0228 |
| 101 | MATH | 508 | 01 | 445-68-9745 |
| 101 | MATH | 508 | 01 | 526-13-8757 |
| 101 | MATH | 508 | 01 | 546-45-5750 |
| 102 | MATH | 521 | 01 | 077-68-9156 |
| 102 | MATH | 521 | 01 | 152-76-8630 |
| 102 | MATH | 521 | 01 | 278-88-7980 |
| 102 | MATH | 521 | 01 | 550-29-9749 |
| 102 | MATH | 521 | 01 | 558-43-9859 |
| 102 | MATH | 521 | 01 | 567-75-3710 |
| 103 | MATH | 633 | 01 | 000-000-001 |
| 104 | MATH | 674 | 01 | 261-73-9432 |
| 104 | MATH | 674 | 01 | 312-94-1786 |
| 104 | MATH | 674 | 01 | 504-78-8469 |
| 104 | MATH | 674 | 01 | 000-00-002 |
| 105 | MATH | 705 | 01 | 000-00-003 |
| 106 | STAT | 528 | 01 | 017-62-8627 |
| 106 | STAT | 528 | 01 | 023-52-7817 |

**Value Table**

| Course ID | Day/Time Wgt | Room Wgt | Scen 1 | Scen 1 | Scen 2 | Scen 2 |
|---|---|---|---|---|---|---|
| 101 | 1 | 0 | 190 | 191 | 095 | 096 |
| 102 | 0.5 | 0.5 | **198** | **201** | **205** | **206** |
| 103 | 1 | 0 | 203 | 204 | 205 | 206 |
| 104 | 0.8 | 0.2 | 190 | 191 | 199 | 200 |
| 105 | 1 | 0 | 217 | 218 | 203 | 204 |
| 106 | 0.5 | 0.5 | **133** | **134** | **160** | **161** |
| 107 | 0.5 | 0.5 | 054 | **062** | **070** | **055** |
| 108 | 0.75 | 0.25 | 199 | 200 | 217 | 218 |
| 109 | 0.75 | 0.25 | 176 | 177 | 133 | 134 |
| 110 | 1 | 0 | 059 | 060 | 061 | 055 |
| 111 | 1 | 0 | 127 | 128 | 131 | 132 |
| 112 | 0.9 | 0.1 | 055 | 056 | 059 | 060 |
| 201 | 0.8 | 0.2 | 089 | 090 | 123 | 124 |
| 202 | 0.9 | 0.1 | 119 | 120 | 087 | 088 |
| 203 | 0.8 | 0.2 | 123 | 124 | 091 | 092 |
| 204 | 0.5 | 0.5 | 245 | **244** | **243** | **241** |
| 205 | 0.9 | 0.1 | 091 | 092 | 093 | 105 |
| 206 | 0.7 | 0.3 | 089 | 090 | 121 | 122 |
| 207 | 1 | 0 | 099 | 100 | 091 | 092 |
| 208 | 0.9 | 0.1 | 119 | 120 | 121 | 122 |
| 209 | 1 | 0 | 100 | 098 | **101** | **099** |
| 210 | 1 | 0 | 123 | 124 | 125 | 093 |
| 211 | 0.9 | 0.1 | 087 | 088 | 089 | 090 |

**Figure 4: Updated CODE DATA Sheet**

## Optimization Subroutine Library (OSL), Mixed Integer Solver

OSL is a powerful mixed integer solver from IBM. It is run on a dedicated WindowsNT workstation in the Center for Modeling, Simulations and Analysis, room 133B in building 640. The solver runs in DOS. The command line to run the solver for the purpose of creating an academic schedule is as follows:

```
oslmslv –maxmin=max  –dspace=10000000  –imaxiter=9999999  –maxsols=9999999
<inputfile> outputfile
```

The input filename is the path and filename placed in Cell C6:C7 on the CODE DATA sheet of the problem generator. The user is referred to that section of the manual for

more information.  The output filename is user defined and will contain the solution to the Mixed Integer Program.  The user is referred to the OSL user manual for further information about OSL.

The solution to the Mixed Integer Program is at the end of the output file.  The solution provides the variable names that describe the course scheduled, as well as the day/time scenario and room group to which the course was assigned.  The first three digits after the letter 'x' are the course ID.  The next three digits give the day/time scenario, and the last digit the room group.  Refer to Tables 1 and 2 for definitions of the various room groups and day/time scenarios.  The scheduler simply translates the variables into an academic course schedule.  The scheduler assigns specific rooms within a particular room group.

If  a variable is returned of the form, x122000n, then the course was not scheduled.  The scheduler has the choice of scheduling the course manually or rerunning the process.  To rerun the process, add or change neutral preferences in the preference entry of the Preference Table for the particular course.  The Preference Table is located on the CODE DATA sheet of the problem generator.

*Caution:  All neutral preferences, for either day/time or rooms, must be in bold font.*

*Note:  Neutral preferences are determined by eliminating the non-preferred day/time scenarios given by the instructor via the electronic questionnaire.*

**Table 1:  Room Groups€**

| Room Group | Classroom Numbers | Capacity |
|:---:|:---:|:---:|
| 1 | 60,62 | 35 |
| 2 | 160-163 | 30 |
| 3 | 260-263 | 28 |
| 4 | 172, 176B | 35&24 |
| 5 | 64A,164A,176A | 10 |
| 6 | Labs 241,265,121 | 25 |
| 7 | Lecture Hall 121 | 54 |
| 8 | Lecture Hall 230 | 54 |
| 9 | Computer Lab 165 | 16 |

**Table 2:  Day/Time Scenarios€**

| | Days of the Week | Start Times (on the hour) | Scenario ID # |
|---|---|---|---|
| | M | 0800 -1600 | 001 - 009 |
| 1 Hour | T | 0800 -1600 | 010 - 018 |
| Class | W | 0800 -1600 | 019 - 027 |
| | R | 0800 -1600 | 028 - 036 |
| | F | 0800 -1600 | 037 - 045 |
| | M | 0800 -1500 | 046 - 053 |
| 2 Hour | T | 0800 -1500 | 054 - 061 |
| Class | W | 0800 -1500 | 062 - 069 |
| | R | 0800 -1500 | 070 - 077 |
| | F | 0800 -1500 | 078 - 085 |
| | MW | 0800 -1500 | 086 - 093 |
| 3 or 4 Hour | TR | 0800 -1500 | 094 - 101 |
| Class | MR | 0800 -1500 | 102 - 109 |
| | MF | 0800 -1500 | 110 -117 |
| | TF | 0800 -1500 | 118 - 125 |
| | MWF | 0800 -1600 | 126 - 134 |
| | MTR | 0800 -1600 | 135 - 143 |
| 3 Hour | MTF | 0800 -1600 | 144 - 152 |
| Class | MWR | 0800 -1600 | 153 - 161 |
| | MRF | 0800 -1600 | 162 - 170 |
| | TWF | 0800 -1600 | 171 - 179 |
| | TRF | 0800 -1600 | 180 - 188 |
| | MTWR | 0800 -1600 | 189 - 197 |
| 4 Hour | MTWF | 0800 -1600 | 198 - 206 |
| Class | MTRF | 0800 -1600 | 207 - 215 |
| | MWRF | 0800 -1600 | 216 - 224 |
| | TWRF | 0800 -1600 | 225 - 233 |
| | MW | 0900 | 234 |
| 6 Hour | MW | 1300 | 235 |
| Lab | TR | 0900 | 236 |
| | TR | 1300 | 237 |
| | M | 0900 | 238 |
| | M | 1300 | 239 |
| 3 Hour | T | 0900 | 240 |
| Lab | T | 1300 | 241 |
| | W | 0900 | 242 |
| | W | 1300 | 243 |
| | R | 0900 | 244 |
| | R | 1300 | 245 |

# Preference Table For Spring Quarter 98 Schedule€

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 101 | 1 | 0 | 190 | 191 | 095 | 096 | 119 | 120 | **5** | **2** | **3** |
| 102 | 0.5 | 0.5 | **198** | **201** | **205** | **206** | **223** | **224** | **5** | **2** | **1** |
| 103 | 1 | 0 | 203 | 204 | 205 | 206 | **201** | **202** | 2 | **1** | **3** |
| 104 | 0.8 | 0.2 | 190 | 191 | 199 | 200 | 189 | **198** | 2 | 3 | **4** |
| 105 | 1 | 0 | 217 | 218 | 203 | 204 | 095 | 096 | 5 | 2 | **3** |
| 106 | 0.5 | 0.5 | **133** | **134** | **160** | **161** | **178** | **179** | **3** | **1** | **2** |
| 107 | 0.5 | 0.5 | 054 | **062** | **070** | **055** | **063** | **071** | 9 | | |
| 108 | 0.75 | 0.25 | 199 | 200 | 217 | 218 | **201** | **219** | 5 | **4** | **2** |
| 109 | 0.75 | 0.25 | 176 | 177 | 133 | 134 | **178** | **179** | 2 | **3** | **5** |
| 110 | 1 | 0 | 059 | 060 | 061 | 055 | 056 | **057** | 9 | | |
| 111 | 1 | 0 | 127 | 128 | 131 | 132 | 133 | 134 | 3 | 4 | 2 |
| 112 | 0.9 | 0.1 | 055 | 056 | 059 | 060 | 061 | **054** | 9 | | |
| 201 | 0.8 | 0.2 | 089 | 090 | 123 | 124 | **121** | **122** | 2 | 1 | **3** |
| 202 | 0.9 | 0.1 | 119 | 120 | 087 | 088 | 121 | 122 | 4 | 1 | **7** |
| 203 | 0.8 | 0.2 | 123 | 124 | 091 | 092 | 121 | 122 | 2 | 3 | **1** |
| 204 | 0.5 | 0.5 | 245 | **244** | **243** | **241** | **239** | **242** | 6 | 7 | 8 |
| 205 | 0.9 | 0.1 | 091 | 092 | 093 | 105 | 106 | **090** | 3 | 4 | 2 |
| 206 | 0.7 | 0.3 | 089 | 090 | 121 | 122 | **091** | **123** | 3 | **1** | **4** |

| 207 | 1 | 0 | 099 | 100 | 091 | 092 | **101** | **093** | **3** | **4** | **2** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 208 | 0.9 | 0.1 | 119 | 120 | 121 | 122 | 123 | 124 | 3 | **2** | **1** |
| 209 | 1 | 0 | 100 | 098 | **101** | **099** | **092** | **093** | **5** | **4** | **2** |
| 210 | 1 | 0 | 123 | 124 | 125 | 093 | **108** | **109** | 5 | **1** | **3** |
| 211 | 0.9 | 0.1 | 087 | 088 | 089 | 090 | 091 | 092 | 3 | **5** | **4** |
| 212 | 0.5 | 0.5 | 030 | | | | | | 7 | **8** | |
| 213 | 0.9 | 0.1 | 087 | 088 | 091 | 092 | 089 | 090 | 4 | 3 | 2 |
| 214 | 0.5 | 0.5 | 011 | 012 | 013 | 029 | 030 | 031 | **4** | **7** | **8** |
| 215 | 1 | 0 | 087 | 088 | 091 | 092 | 093 | | 3 | 2 | 1 |
| 216 | 0.5 | 0.5 | 075 | **076** | **073** | **074** | **071** | **072** | 6 | | |
| 217 | 1 | 0 | 093 | 091 | 092 | 089 | 090 | **088** | 5 | 3 | 2 |
| 218 | 0.75 | 0.25 | 203 | 204 | 205 | 206 | 201 | 202 | 6 | **4** | **1** |
| 219 | 1 | 0 | 199 | 200 | 198 | 203 | 204 | | **5** | **3** | **2** |
| 220 | 0.99 | 0.01 | 203 | 204 | 199 | 200 | 198 | | 4 | 3 | 2 |
| 221 | 1 | 0 | 095 | | | | | | **5** | **1** | **4** |
| 222 | 0.75 | 0.25 | 120 | 121 | 087 | 088 | **089** | **090** | 3 | 2 | **5** |
| 223 | 0.9 | 0.1 | 099 | 100 | 121 | 122 | **097** | **098** | 3 | **5** | **1** |
| 224 | 1 | 0 | 123 | 124 | 121 | 122 | 091 | 092 | 3 | 5 | 2 |
| 225 | 0.5 | 0.5 | 245 | **244** | **243** | **241** | **239** | **242** | 6 | | |
| 226 | 0.5 | 0.5 | 030 | | | | | | 8 | **7** | |
| 227 | 0.5 | 0.5 | 032 | **031** | **033** | **030** | **034** | **029** | 6 | **4** | 1 |
| 228 | 0.75 | 0.25 | 089 | 090 | 119 | 120 | **121** | **122** | 3 | 2 | **1** |
| 229 | 1 | 0 | 119 | 120 | 123 | 124 | **087** | **088** | **5** | **1** | **2** |
| 301 | 0.5 | 0.5 | **207** | **208** | **209** | **210** | 211 | 212 | **1** | **5** | **4** |
| 302 | 0.8 | 0.2 | 199 | 200 | 203 | 204 | **205** | **206** | 5 | **3** | **2** |
| 303 | 0.5 | 0.5 | **207** | **208** | **209** | **210** | 211 | 212 | **1** | **5** | **4** |
| 304 | 1 | 0 | 231 | 230 | 229 | 228 | 227 | 226 | **5** | **1** | **2** |
| 305 | 1 | 0 | 051 | 052 | 048 | 047 | 046 | | **3** | **1** | **2** |
| 306 | 1 | 0 | 236 | 237 | **234** | **235** | | | 9 | | |

| 307 | 0.5 | 0.5 | 190 | 191 | 192 | 193 | **194** | **195** | | 2 | 3 | **1** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 308 | 0.5 | 0.5 | 027 | 026 | | | | | | 7 | 8 | |
| 309 | 1 | 0 | 087 | 088 | 089 | 090 | 091 | 092 | | **5** | **1** | **4** |
| 310 | 1 | 0 | 095 | 096 | 097 | 098 | 099 | 100 | | **5** | **1** | **4** |
| 311 | 0.5 | 0.5 | 199 | 200 | 208 | 209 | **217** | **218** | | 2 | **1** | **5** |
| 312 | 0.5 | 0.5 | **226** | **227** | **228** | **229** | **230** | **231** | | 3 | **1** | **2** |
| 313 | 1 | 0 | 199 | 200 | 201 | 202 | 203 | 204 | | 2 | 3 | **4** |
| 314 | 0.5 | 0.5 | 131 | 132 | **130** | **129** | **128** | **127** | | 2 | **1** | **3** |
| 315 | 0.5 | 0.5 | 241 | 245 | **242** | **244** | | | | **2** | **1** | **3** |
| 316 | 1 | 0 | 190 | 191 | 194 | 195 | 189 | | | 2 | 3 | **1** |
| 317 | 0.5 | 0.5 | **001** | **002** | **003** | **004** | **005** | **006** | | **7** | **8** | |
| 401 | 0.5 | 0.5 | 075 | 076 | | | | | | 7 | 8 | |
| 402 | 0.9 | 0.1 | 097 | 098 | 099 | 100 | 095 | 096 | | 4 | 3 | 2 |
| 403 | 0.9 | 0.1 | 087 | 088 | 099 | 100 | 091 | 092 | | 4 | 3 | 2 |
| 404 | 0.9 | 0.1 | 087 | 088 | 099 | 100 | 091 | 092 | | 1 | 2 | 4 |
| 405 | 0.5 | 0.5 | 029 | 030 | 038 | 039 | 002 | 003 | | 5 | 7 | 8 |
| 406 | 0.9 | 0.1 | 226 | 227 | 228 | 229 | 225 | | | 5 | 4 | 2 |
| 407 | 0.8 | 0.2 | 091 | 092 | 099 | 100 | 087 | 088 | | 4 | 2 | 3 |
| 408 | 0.7 | 0.3 | 091 | 092 | 099 | 100 | 087 | 088 | | 4 | 2 | 3 |
| 409 | 0.8 | 0.2 | 094 | 086 | **126** | **095** | **087** | **096** | | 4 | **3** | **2** |
| 501 | 1 | 0 | 087 | 088 | 089 | 090 | 091 | 092 | | 1 | 2 | 5 |
| 502 | 0.8 | 0.2 | 020 | 021 | 011 | 012 | 029 | 030 | | 2 | 3 | **1** |
| 503 | 0.5 | 0.5 | 095 | 096 | 099 | 100 | 087 | 088 | | 3 | 2 | 1 |
| 504 | 1 | 0 | 095 | 096 | 097 | 098 | 099 | 100 | | 3 | **2** | 1 |
| 505 | 0.5 | 0.5 | 086 | 126 | **087** | **088** | **127** | **128** | | 3 | **2** | 1 |
| 601 | 0.85 | 0.15 | 131 | 132 | 127 | 128 | 099 | 100 | | 3 | **2** | 1 |
| 602 | 0.5 | 0.5 | **094** | **095** | **096** | **097** | **098** | **099** | | 5 | 4 | 3 |
| 603 | 0.5 | 0.5 | **086** | **087** | **088** | **089** | **090** | **091** | | 5 | 3 | 1 |
| 604 | 0.5 | 0.5 | **094** | **095** | **096** | **097** | **098** | **099** | | 5 | 4 | 2 |

| 605 | 0.5 | 0.5 | **086** | **087** | **088** | **089** | **090** | **091** | | **5** | **3** | **1** |
|-----|-----|-----|---------|---------|---------|---------|---------|---------|---|-----|-----|-----|
| 606 | 0.9 | 0.1 | 199 | 200 | 087 | 088 | **201** | **089** | | 3 | 2 | **1** |
| 607 | 0.5 | 0.5 | **198** | **199** | **200** | **201** | **202** | **203** | | 3 | 2 | **4** |
| 608 | 0.35 | 0.65 | 199 | 200 | 203 | 204 | 190 | 191 | | 3 | 2 | **4** |
| 609 | 0.5 | 0.5 | 099 | 100 | 119 | 120 | 230 | 231 | | 3 | 2 | 4 |
| 610 | 1 | 0 | 238 | 239 | 241 | 240 | 234 | 242 | | **6** | **7** | **8** |
| 611 | 0.5 | 0.5 | 190 | 191 | 192 | 193 | 194 | 195 | | 3 | **2** | **1** |

# Appendix J

# ED Plans Query For Spring Quarter 98 Schedule

| | | | | |
|---|---|---|---|---|
| 101 | MATH | 508 | 01 | 002-78-1969 |
| 101 | MATH | 508 | 01 | 061-58-6522 |
| 101 | MATH | 508 | 01 | 116-56-4832 |
| 101 | MATH | 508 | 01 | 226-27-8496 |
| 101 | MATH | 508 | 01 | 408-55-1091 |
| 101 | MATH | 508 | 01 | 417-19-0228 |
| 101 | MATH | 508 | 01 | 445-68-9745 |
| 101 | MATH | 508 | 01 | 526-13-8757 |
| 101 | MATH | 508 | 01 | 546-45-5750 |
| 102 | MATH | 521 | 01 | 077-68-9156 |
| 102 | MATH | 521 | 01 | 152-76-8630 |
| 102 | MATH | 521 | 01 | 278-88-7980 |
| 102 | MATH | 521 | 01 | 550-29-9749 |
| 102 | MATH | 521 | 01 | 558-43-9859 |
| 102 | MATH | 521 | 01 | 567-75-3710 |
| 103 | MATH | 633 | 01 | 000-000-001 |
| 104 | MATH | 674 | 01 | 261-73-9432 |

| 104 | MATH | 674 | 01 | 312-94-1786 |
| 104 | MATH | 674 | 01 | 504-78-8469 |
| 104 | MATH | 674 | 01 | 000-00-002 |
| 105 | MATH | 705 | 01 | 000-00-003 |
| 106 | STAT | 528 | 01 | 017-62-8627 |
| 106 | STAT | 528 | 01 | 023-52-7817 |
| 106 | STAT | 528 | 01 | 263-63-8302 |
| 106 | STAT | 528 | 01 | 399-68-3166 |
| 106 | STAT | 528 | 01 | 414-49-4391 |
| 106 | STAT | 528 | 01 | 459-79-1577 |
| 106 | STAT | 528 | 01 | 460-33-1803 |
| 106 | STAT | 528 | 01 | 480-60-4053 |
| 107 | STAT | 528 | 91 | 017-62-8627 |
| 107 | STAT | 528 | 91 | 023-52-7817 |
| 107 | STAT | 528 | 91 | 263-63-8302 |
| 107 | STAT | 528 | 91 | 399-68-3166 |
| 107 | STAT | 528 | 91 | 414-49-4391 |
| 107 | STAT | 528 | 91 | 459-79-1577 |
| 107 | STAT | 528 | 91 | 460-33-1803 |
| 107 | STAT | 528 | 91 | 480-60-4053 |
| 108 | STAT | 583 | 01 | 269-70-2117 |
| 108 | STAT | 583 | 01 | 453-13-1389 |
| 108 | STAT | 583 | 01 | 529-43-6216 |

| 108 | STAT | 583 | 01 | 555-85-8988 |
| 109 | STAT | 696 | 01 | 135-66-3641 |
| 109 | STAT | 696 | 01 | 145-76-4239 |
| 109 | STAT | 696 | 01 | 155-62-9418 |
| 109 | STAT | 696 | 01 | 167-52-5679 |
| 109 | STAT | 696 | 01 | 197-48-0279 |
| 109 | STAT | 696 | 01 | 230-25-4803 |
| 109 | STAT | 696 | 01 | 288-58-2383 |
| 109 | STAT | 696 | 01 | 298-72-3524 |
| 109 | STAT | 696 | 01 | 307-90-7774 |
| 109 | STAT | 696 | 01 | 323-80-4274 |
| 109 | STAT | 696 | 01 | 334-60-9745 |
| 109 | STAT | 696 | 01 | 407-06-8356 |
| 109 | STAT | 696 | 01 | 410-43-5582 |
| 109 | STAT | 696 | 01 | 426-06-7661 |
| 109 | STAT | 696 | 01 | 441-76-2966 |
| 109 | STAT | 696 | 01 | 452-37-8068 |
| 109 | STAT | 696 | 01 | 452-93-3772 |
| 110 | STAT | 696 | 91 | 135-66-3641 |
| 110 | STAT | 696 | 91 | 145-76-4239 |
| 110 | STAT | 696 | 91 | 155-62-9418 |
| 110 | STAT | 696 | 91 | 167-52-5679 |
| 110 | STAT | 696 | 91 | 197-48-0279 |

| 110 | STAT | 696 | 91 | 230-25-4803 |
| 110 | STAT | 696 | 91 | 288-58-2383 |
| 110 | STAT | 696 | 91 | 298-72-3524 |
| 110 | STAT | 696 | 91 | 307-90-7774 |
| 110 | STAT | 696 | 91 | 323-80-4274 |
| 110 | STAT | 696 | 91 | 334-60-9745 |
| 110 | STAT | 696 | 91 | 407-06-8356 |
| 110 | STAT | 696 | 91 | 410-43-5582 |
| 110 | STAT | 696 | 91 | 426-06-7661 |
| 110 | STAT | 696 | 91 | 441-76-2966 |
| 110 | STAT | 696 | 91 | 452-37-8068 |
| 110 | STAT | 696 | 91 | 452-93-3772 |
| 111 | STAT | 696 | 02 | 493-64-0852 |
| 111 | STAT | 696 | 02 | 507-88-4212 |
| 111 | STAT | 696 | 02 | 508-76-1824 |
| 111 | STAT | 696 | 02 | 512-78-6647 |
| 111 | STAT | 696 | 02 | 521-33-4756 |
| 111 | STAT | 696 | 02 | 528-43-6241 |
| 111 | STAT | 696 | 02 | 537-92-9102 |
| 111 | STAT | 696 | 02 | 540-08-9450 |
| 111 | STAT | 696 | 02 | 541-13-1388 |
| 111 | STAT | 696 | 02 | 553-91-1466 |
| 111 | STAT | 696 | 02 | 594-28-2049 |

| 111 | STAT | 696 | 02 | 594-54-0505 |
|-----|------|-----|----|-------------|
| 111 | STAT | 696 | 02 | 999-00-0304 |
| 111 | STAT | 696 | 02 | 999-00-0305 |
| 111 | STAT | 696 | 02 | 999-00-0314 |
| 111 | STAT | 696 | 02 | 999-00-0315 |
| 112 | STAT | 696 | 92 | 468-84-9447 |
| 112 | STAT | 696 | 92 | 493-64-0852 |
| 112 | STAT | 696 | 92 | 507-88-4212 |
| 112 | STAT | 696 | 92 | 508-76-1824 |
| 112 | STAT | 696 | 92 | 512-78-6647 |
| 112 | STAT | 696 | 92 | 521-33-4756 |
| 112 | STAT | 696 | 92 | 528-43-6241 |
| 112 | STAT | 696 | 92 | 537-92-9102 |
| 112 | STAT | 696 | 92 | 540-08-9450 |
| 112 | STAT | 696 | 92 | 541-13-1388 |
| 112 | STAT | 696 | 92 | 553-91-1466 |
| 112 | STAT | 696 | 92 | 594-28-2049 |
| 112 | STAT | 696 | 92 | 594-54-0505 |
| 112 | STAT | 696 | 92 | 999-00-0304 |
| 112 | STAT | 696 | 92 | 999-00-0305 |
| 112 | STAT | 696 | 92 | 999-00-0314 |
| 112 | STAT | 696 | 92 | 999-00-0315 |
| 112 | STAT | 696 | 92 | 468-84-9447 |

| 201 | CSCE | 532 | 01 | 413-02-6062 |
|-----|------|-----|-----|-------------|
| 201 | CSCE | 532 | 01 | 543-17-5520 |
| 201 | CSCE | 532 | 01 | 999-00-0280 |
| 201 | CSCE | 532 | 01 | 999-00-0311 |
| 201 | CSCE | 532 | 01 | 999-00-0312 |
| 202 | CSCE | 544 | 01 | 002-78-1969 |
| 202 | CSCE | 544 | 01 | 005-74-7174 |
| 202 | CSCE | 544 | 01 | 093-54-0888 |
| 202 | CSCE | 544 | 01 | 183-64-2498 |
| 202 | CSCE | 544 | 01 | 211-58-1799 |
| 202 | CSCE | 544 | 01 | 252-27-3119 |
| 202 | CSCE | 544 | 01 | 269-70-2117 |
| 202 | CSCE | 544 | 01 | 296-60-5633 |
| 202 | CSCE | 544 | 01 | 310-76-0949 |
| 202 | CSCE | 544 | 01 | 311-82-3180 |
| 202 | CSCE | 544 | 01 | 334-72-1062 |
| 202 | CSCE | 544 | 01 | 381-74-5351 |
| 202 | CSCE | 544 | 01 | 392-78-2316 |
| 202 | CSCE | 544 | 01 | 413-02-6062 |
| 202 | CSCE | 544 | 01 | 414-17-2236 |
| 202 | CSCE | 544 | 01 | 467-17-0758 |
| 202 | CSCE | 544 | 01 | 473-86-0371 |
| 202 | CSCE | 544 | 01 | 480-86-8957 |

| 202 | CSCE | 544 | 01 | 516-13-9290 |
| 202 | CSCE | 544 | 01 | 520-17-9499 |
| 202 | CSCE | 544 | 01 | 527-96-9291 |
| 202 | CSCE | 544 | 01 | 528-43-9574 |
| 202 | CSCE | 544 | 01 | 539-64-0152 |
| 202 | CSCE | 544 | 01 | 555-85-8988 |
| 202 | CSCE | 544 | 01 | 559-53-3283 |
| 202 | CSCE | 544 | 01 | 574-60-5692 |
| 202 | CSCE | 544 | 01 | 598-09-4953 |
| 202 | CSCE | 544 | 01 | 600-48-5415 |
| 202 | CSCE | 544 | 01 | 999-00-0301 |
| 202 | CSCE | 544 | 01 | 999-00-0309 |
| 202 | CSCE | 544 | 01 | 999-00-0310 |
| 202 | CSCE | 544 | 01 | 999-00-0317 |
| 202 | CSCE | 544 | 01 | 999-00-0318 |
| 203 | CSCE | 595 | 01 | 005-74-7174 |
| 203 | CSCE | 595 | 01 | 183-64-2498 |
| 203 | CSCE | 595 | 01 | 269-70-2117 |
| 203 | CSCE | 595 | 01 | 352-66-0972 |
| 203 | CSCE | 595 | 01 | 413-02-6062 |
| 203 | CSCE | 595 | 01 | 414-17-2236 |
| 203 | CSCE | 595 | 01 | 467-17-0758 |
| 203 | CSCE | 595 | 01 | 480-86-8957 |

| 203 | CSCE | 595 | 01 | 529-43-6216 |
| --- | --- | --- | --- | --- |
| 203 | CSCE | 595 | 01 | 999-00-0293 |
| 203 | CSCE | 595 | 01 | 999-00-0307 |
| 203 | CSCE | 595 | 01 | 999-00-0309 |
| 204 | CSCE | 595 | 91 | 005-74-7174 |
| 204 | CSCE | 595 | 91 | 183-64-2498 |
| 204 | CSCE | 595 | 91 | 269-70-2117 |
| 204 | CSCE | 595 | 91 | 352-66-0972 |
| 204 | CSCE | 595 | 91 | 413-02-6062 |
| 204 | CSCE | 595 | 91 | 414-17-2236 |
| 204 | CSCE | 595 | 91 | 467-17-0758 |
| 204 | CSCE | 595 | 91 | 480-86-8957 |
| 204 | CSCE | 595 | 91 | 529-43-6216 |
| 204 | CSCE | 595 | 91 | 999-00-0293 |
| 204 | CSCE | 595 | 91 | 999-00-0307 |
| 204 | CSCE | 595 | 91 | 999-00-0309 |
| 205 | CSCE | 623 | 01 | 005-74-7174 |
| 205 | CSCE | 623 | 01 | 013-52-7106 |
| 205 | CSCE | 623 | 01 | 183-64-2498 |
| 206 | CSCE | 646 | 01 | 005-74-7174 |
| 206 | CSCE | 646 | 01 | 013-52-7106 |
| 206 | CSCE | 646 | 01 | 211-58-1799 |
| 206 | CSCE | 646 | 01 | 296-60-5633 |

| 206 | CSCE | 646 | 01 | 381-74-5351 |
| 206 | CSCE | 646 | 01 | 414-17-2236 |
| 206 | CSCE | 646 | 01 | 473-86-0371 |
| 206 | CSCE | 646 | 01 | 574-60-5692 |
| 206 | CSCE | 646 | 01 | 999-00-0286 |
| 206 | CSCE | 646 | 01 | 999-00-0309 |
| 206 | CSCE | 646 | 01 | 999-00-0310 |
| 206 | CSCE | 646 | 01 | 999-00-0312 |
| 207 | CSCE | 654 | 01 | 093-54-0888 |
| 207 | CSCE | 654 | 01 | 252-27-3119 |
| 207 | CSCE | 654 | 01 | 296-60-5633 |
| 207 | CSCE | 654 | 01 | 311-82-3180 |
| 207 | CSCE | 654 | 01 | 334-72-1062 |
| 207 | CSCE | 654 | 01 | 370-70-6185 |
| 207 | CSCE | 654 | 01 | 389-66-4949 |
| 207 | CSCE | 654 | 01 | 392-78-2316 |
| 207 | CSCE | 654 | 01 | 467-17-0758 |
| 207 | CSCE | 654 | 01 | 473-86-0371 |
| 207 | CSCE | 654 | 01 | 480-86-8957 |
| 207 | CSCE | 654 | 01 | 520-17-9499 |
| 207 | CSCE | 654 | 01 | 527-96-9291 |
| 207 | CSCE | 654 | 01 | 528-43-9574 |
| 207 | CSCE | 654 | 01 | 555-85-8988 |

| 207 | CSCE | 654 | 01 | 559-53-3283 |
| 207 | CSCE | 654 | 01 | 999-00-0286 |
| 207 | CSCE | 654 | 01 | 999-00-0301 |
| 207 | CSCE | 654 | 01 | 999-00-0307 |
| 207 | CSCE | 654 | 01 | 999-00-0310 |
| 207 | CSCE | 654 | 01 | 999-00-0311 |
| 207 | CSCE | 654 | 01 | 999-00-0312 |
| 207 | CSCE | 654 | 01 | 999-00-0317 |
| 207 | CSCE | 654 | 01 | 999-00-0318 |
| 207 | CSCE | 654 | 01 | 999-00-0319 |
| 208 | CSCE | 656 | 01 | 252-27-3119 |
| 208 | CSCE | 656 | 01 | 453-13-1389 |
| 208 | CSCE | 656 | 01 | 548-85-3519 |
| 209 | CSCE | 682 | 01 | 310-76-0949 |
| 209 | CSCE | 682 | 01 | 510-84-9117 |
| 209 | CSCE | 682 | 01 | 526-75-7783 |
| 209 | CSCE | 682 | 01 | 600-48-5415 |
| 210 | CSCE | 683 | 01 | 310-76-0949 |
| 210 | CSCE | 683 | 01 | 453-13-1389 |
| 210 | CSCE | 683 | 01 | 543-17-5520 |
| 211 | CSCE | 686 | 01 | 013-52-7106 |
| 211 | CSCE | 686 | 01 | 211-58-1799 |
| 211 | CSCE | 686 | 01 | 296-60-5633 |

| 211 | CSCE | 686 | 01 | 310-76-0949 |
| 211 | CSCE | 686 | 01 | 352-66-0972 |
| 211 | CSCE | 686 | 01 | 543-17-5520 |
| 211 | CSCE | 686 | 01 | 548-85-3519 |
| 211 | CSCE | 686 | 01 | 594-54-0505 |
| 211 | CSCE | 686 | 01 | 999-00-0307 |
| 212 | CSCE | 698 | 01 | 005-74-7174 |
| 212 | CSCE | 698 | 01 | 013-52-7106 |
| 212 | CSCE | 698 | 01 | 183-64-2498 |
| 212 | CSCE | 698 | 01 | 211-58-1799 |
| 212 | CSCE | 698 | 01 | 252-27-3119 |
| 212 | CSCE | 698 | 01 | 269-70-2117 |
| 212 | CSCE | 698 | 01 | 296-60-5633 |
| 212 | CSCE | 698 | 01 | 310-76-0949 |
| 212 | CSCE | 698 | 01 | 312-94-1786 |
| 212 | CSCE | 698 | 01 | 334-72-1062 |
| 212 | CSCE | 698 | 01 | 352-66-0972 |
| 212 | CSCE | 698 | 01 | 381-74-5351 |
| 212 | CSCE | 698 | 01 | 413-02-6062 |
| 212 | CSCE | 698 | 01 | 414-17-2236 |
| 212 | CSCE | 698 | 01 | 453-13-1389 |
| 212 | CSCE | 698 | 01 | 467-17-0758 |
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